THE SCAB OF POTATO (*Solanum tuberosum*) CAUSED BY *Streptomyces scabies* AND ITS CONTROL

By

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Plant Pathology

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Shambat

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جرب البطاطس الذي تسببه البكتريا Streptomyces scabies وكافحته

ورد

(1999 - 1996)

(2007)
God said (And in the earth are tracts (diverse though) neighbouring, and gardens of vines and fields sown with corn, and palm trees, growing out of single roots or otherwise: watered with the same water, yet some of them we make more excellent than others to eat. Behold, verily in these things there are signs for those who understand).

DEDICATION

To My Family With Deep Love And Good Wishes
ACKNOWLEDGMENTS

Blessings be to Allah, and prayers and greetings upon the prophet Mohammed and his companions. I do greatly thank The God who helped me to do this thesis.

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My great thanks to all who assisted me while doing the research and to all who taught me even a letter.
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ABSTRACT

The title of the study is the scab of potato (*Solanum tuberosum*) caused by *Streptomyces scabies* and its control.

The objective of the present work was to study the performance of potato grown under contaminated condition with common scab (*Streptomyces scabies*) and to assess the effect of some cultural practices. The work also involved the study of the use of neem seed extract to control the causal organism of common scab (*Streptomyces scabies*). Meanwhile, the correlation between economic losses due to infection by the disease (common scab) and other factors associated with this problem was also studied.

In both seasons, all the studied parameters (rate of general infections, percentage of high infections, general rate of infection, percentage of high infection, percentage of medium infection, percentage of low infection, percentage of high infection among large size tubers, percentage of medium infection among large size tubers, percentage of low infection among large size tubers, percentage of high infection among medium size tubers, percentage of medium infection among medium size tubers, percentage of low infection among medium size tubers, percentage of high infection among small size tubers, percentage of medium infection among small size tubers, percentage of low infection among small size tubers, total yield (ton/fed), effect of neem correlation duration of application period and their interaction on number of colonies of *Streptomyces scabies*) were significantly affected by varieties, cultural practices (irrigation and fertilization) and their interaction. The performance of Alpha variety in its both conditions (control and contaminated) a significantly better in resisting
the common scab disease (as shown the studied parameter). The Draga variety was the best yield in the first season while Diamond variety was the best in the second season. On the other hand, application of heavy irrigation and fertilization (6 days irrigation and 130.4 N kg/fed) resulted in a significantly low resistance to the disease as compared to low irrigation and fertilization (8 days irrigation and 86.9 N kg/fed).

Pathogenicity of the causal organism was tested on studied varieties in the field. The bacteria causing the disease has showed causing disease for the plants in the field.

Application of neem seed extraction showed a significantly positive effect on controlling the common scab disease as compared to check treatment. The concentration 10 % was significantly higher in inhibiting the causal organism, followed by 5 % concentration. Also the study showed that the inhibition of *S. scabies* was significantly decreased with the time (1 week, 2 weeks and 3 weeks).

The study also showed a significantly positive correlation between economic losses due to infection (*S. scabies*) and cultivated seeds, seed source, fertilizer application, distance of land from Nile, infected tubers and soil type. Meanwhile, the study reflected a significantly negative correlation between economic losses and irrigation intervals.

The study focused on using husbandry practices to prove that:

- It is easy and accessible.
- It is cheap.
- It doesn’t need high technology.
- Saves time and money.
- Prevent consumers from the negative effects of pesticides
• Save the money which could be used for purchasing pesticides for
  rehabilitating plant’s environment.
Abstract

The title of the study is The Bacteria (*Streptomyces scabies*) the scab of potato and its control. The study focused on using husbandry practices to prove that:

- It is easy and accessible.
- It is cheap.
- It doesn’t need high technology.
- Saves time and money.
- Prevent human kinds from the negative effects of pesticides.
- Save the money which could be used for purchasing pesticides for rehabilitating plant’s environment.

The experiment was conducted in the areas of potato cultivation North of Khartoum State (Al Shihanab region). Three varieties were cultivated, namely Alpha, Draga and Diamond. Two intervals of irrigation and additional dose of fertilizer for two conseqenced seasons was used.

The study proved that watering and fertilizing with greater doses has negative significant effect in resisting the disease. While the little doses of watering and fertilizing is relatively the best in resisting the disease.

Alpha variety has been the best in resisting the disease, that is why the farmers prefer it. Also it is the best to be stored and resist pests. On the other hand productivity scale the Draga variety is the best in the first season while Diamond variety was the best in the second season.

Pathogenicity potential was tested upon the caused organism for the studied varieties at the field. The bacteria causing the disease has showed potentiality in causing disease for the plants in the field, after it has been
isolated from the infected tubers at the begining and then germinated in (P.D.A) media labourately and it is well developed.

Labourately the study showed the effectiveness of water extract of Neem’s seeds in suppressing the germination of the bacteria that cause common scab at 5 % and 10 % concentrations, compared with untreated dishes.

The questionnaire, which was distributed in the potato cultivation areas to assess the range of economical losses from infected tubers (common scab). Showed that there has been a significant difference between the rate of infection and sales prices. That is to say the prices decreases when infection increases. Also there have been significant differences among the other factors. But there has not been a significant difference between the economical losses of the disease, sowing date, cutter tool sterilizing and soil flooding.
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CHAPTER ONE
INTRODUCTION

Potato, (*Solanum tuberosum* “L.”), is the world fourth most important crop after rice, wheat and maize (Hawkes, 1989). In its original home in South America, potatoes are grown in the cooler temperate regions of the Andes mountains in Venezuela, Colombia, Ecuador, Bolivia and North Argentina where sufficient moisture is available. It grows best under long-day condition (Mohamed, 1986).

Like many of the world’s major agricultural products, potatoes have attained their widest use and importance in lands far from their place of origin. They were first introduced into Europe by the Spaniards in 1570 and have been selected and adopted over the years for their growing condition in the cool climate countries. Gradually it became stable food crop in Europe, especially in Germany, Russia and Ireland. At the present time, Potato is grown worldwide and is considered as a major food in most countries with temperate climate (Rich, 1983). It is also commonly grown in tropical regions in Winter or high altitudes (Martin and French, 1985; Njoroge, 1993).

The potato has made very little progress in the world’s hunger belt where it could add substantially and advantageously to the food supplies with its high food yield per feddan (1 Feddan = 1.036 Acres). Its ample carbohydrate content well balanced protein and high levels of vitamins C and B (Mohamed, 1986).
One factor which greatly promoted the spread of potato cultivation was the Industrial Revolution in the first half of the nineteenth century (Burton, 1966).

From 1974 the total area in the world cropped with potatoes decreased by 8%, but the total production increased by 6% due to increase in yield. In developed countries the area increased by almost 10% and total production by as much as 35% (Vanderzaag, 1989).

The potato was introduced in Sudan during 1920 and grown in scattered land strips in the outskirts of Khartoum North city (Omer, 1986).

Potato production in Sudan in the past was confined to small limited areas North of Khartoum. The main production areas are North of Khartoum along both banks of the Nile in Shendi and Atabra areas, Jebel Marra in Western Sudan and Tokar and Gash Deltas in Eastern Sudan. Still Khartoum municipality as we know takes the lead (Musa, 1989). Recently potato has become a popular vegetable in the country. Its importance has markedly increased due to expansion in urban centers, as a result of migration from rural areas, increase in population, general awareness of the nutritional value of vegetables, general income improvement of most sectors, besides other socio-economic changes that dictated some shifts from traditional meals in the Sudanese house (Geneif and Sidri, 1989).

Statistics already indicated that potato production and consumption are on the increase with increase in urbanization and higher living standards (Musa, 1989).

The area under cultivation has been steadily increasing and at present the total area of production is about 5600 Feddan with and average yield of about 6 tons per Feddan (Mohamed, 1986).
An estimated area of 8000 Feddan (3200 Ha) of Potato area grown production takes place on irrigated land along the river Nile in the winter season from November to March. Main production area is directly North of Khartoum. As the seeds are cut in small pieces, planting is usually done to a seed rate of 500 kg per Feddan for wares potatoes. This means that roughly 4000 tons of seed potato are required every year. Up to 1988 there was no tradition of local seed production (Morrenhof, 1996).

Most of the seed needed for planting was imported from Holland through Agricultural Bank of Sudan (ABS) till it stopped in 1992, this situation encouraged the private sector to enter into local seed production through multiplication of imported basic seed (class E). Some farmers save their own seed from previous season. In Jabal Mara the situation is different where the farmers use unknown varieties, highly infected with viruses due to successive multiplication over the years since 1930, they harvest the big tubers and leave the small ones in the ground to grow when it rains (Ali, 2000). Around 1500 Tons of Potato seed was imported yearly (Morrenhof, 1996).

As a nutritious, rapid growing and highly productive food crop, potato can play an important role in diversifying cropping systems and food supplies in the country (Geneif and Sidri, 1989).

In the Sudan Potatoes suffer from many pests and diseases like potato virus diseases and their aphid vectors are serious problems. Natural occurrence of Potato virus S (PVS), potato virus X (PVX) potato virus Y (PVY) and potato leafroll virus (PLRV) were reported in important areas of production in the country. Other pathogens such as *Rhizoctonia solani* and *Streptomyces scabies* are present (Geneif and Sidri, 1989).
In the Sudan, currently *Streptomyces scabies* has become very dangerous and a devastating disease on potato. All varieties are susceptible to this disease. However, common scab disease of potatoes caused by *S. scabies* (bacteria), cause seed decay and reduce market value.

Thus the present study was undertaken with the following main objectives:

- To study the effect of irrigation and fertilization on the control of common scab of potato.

- To study the possibility of using Neem seed extract as a natural pesticide to control potato diseases.

- To assess the effect of the disease on crop demand.

- Decrease the uses of pesticides and avoid their problems and side effect.

- Encourage and open the door for researchers and farmers for using easy, uncompound, and useful ways for controlling diseases.
CHAPTER TWO
LITERATURE REVIEW

2.1 The potato

Potato, (*Solanum tuberosum* “L.”), is the world’s fourth most important crop after rice, wheat and maize. It is grown chiefly in the temperate zone. Potato belongs to family *Solanaceae*. This family also includes several plants which are of high food value. The genus *Solanum* which includes the potato, comprises 2000 species (Hawkes, 1989). Nearly 200 of these are tuber bearing (Whitehead et al., 1953). The plants belonging to the genus are mostly herbs, shrubs and a few are small trees.

Rich (1983) mentioned that it is one of mankind’s most valuable foods, is produced in 130 countries where three-fourth of world's population lives. More than 90 of which are located in the tropical and subtropical Zones. Although most of the production still comes from the temperate Zone in the industrialized Countries, mainly in Asia (Vanderzaag, 1991). The geographic range of the potato is almost worldwide, it is grown as a major source of food in most countries with a temperate climate.

Abdalla and Elshafie (1983) reported that, the potato was introduced into the Sudan during the first world war, amongst other food crops introduced from the temperate countries. On the other hand it suffers from many organisms causing several diseases and the common scab one of them (Vanderzaag, 1989).

The predominant variety grown in Northern Sudan is Alpha. It is preferred by small farmers for its good storability in pit and cold storage. At
Jebel Mara in Western Sudan the variety grown is of unknown origin. Some new other varieties with high yield include Diamond, famoza, Ajax, Draga, Turbo, Akira, Maradona and Oblex, (Ali, 2000).

2.1.1 Nutritional Value

It contains high quality protein and substantial amounts of essential vitamins, minerals, and trace elements. Protein content of potato is equal to yam and is almost twice that of sweet potato and cassava. More over, on a cooked basis, the potato compares with other major staples, such as boiled rice and cereals cooked as porridges (CIP, 1984).

Redcliffe (1949) reported that potato is a source of nitrogen, vitamin C and starch, which forms by far the greater part of the dry matter of the tuber. Because of this it is natural that some attention should have been paid to the possibility of using the potato as a source of starch for industrial purposes. In industry the starch may be used as such, or it may be used as raw material for the production of substances such as alcohol.

2.1.2 Bacterial Diseases of potato

The potato is susceptible to a great many diseases, some of which are widespread and others are localized. The causal agents of these diseases include bacteria, fungi, viruses, micoplasmas, viroids, and nematodes. And other groups of disorders, called non infectious diseases, include those due to unfavorable environment, faulty nutrition, or other abiotic factors. (Dykstra, 1948; Whitehead et al., 1953; Dykstra and Reid, 1956; Houghland et al., 1957; Kehr et al., 1964).

The bacteria which attack potatoes are a comparatively small but important group of pathogens. Bacteria are single–celled, microscopic organisms which reproduce by fission. They belong to the class
Schizomycetes, sometimes referred to as the fission fungi, all are non spore forming short rods in the order Eubacterial with the exception of Streptomyces scabies, the causal agent of common scab (Dowson, 1957; Elliott, 1951). All are gram-negative except Corynebacteri um sepedonicum, the causal, agent of ring rot (Rich, 1983).

Anonymous (1960) listed approximately 160 diseases and disorders of Solanum tuberosum. About 50 are caused by fungi, 30 viruses, 10 by bacteria, and another 50 or so are either non parasitic or due to unknown causes. Several others are due to nematodes or insects, and one is caused by dodder.

Streptomyces is often classified with the fungi rather than with the bacteria (Anonymous, 1960; Drechsler, 1919). It produces rudimentary hyphae which produces spores by the formation of separations. It is also classified with the bacteria. It belongs to the order Actinomycetales and family Streptomycetaceae (Breed et al., 1957; Rich, 1968; Walker, 1969).

2.2 The Bacteria Streptomyces scabies (Causal Agent)

Thaxter (1892) reported that the causal agent of common scab is the actinomycete Streptomyces scabies. Thaxter first identified and described the pathogen in 1890, calling it Oospora scabs. The name was changed to Actinomyces scabs in 1914. Some writer classify it as abacterium (Breed et al., 1945; Walker, 1969) while others, including the United States Department of Agriculture, usually classify it as fungus (Anonymous, 1960; Drechsler, 1919; Brien and Rich 1976). It produces a rudimentary, coiled hyaline mycelium characteristic of fungi, septations then form resulting in one – celled hyaline spores $1 – 2 \times 0.6 – 0.7 \mu$ resembling bacteria. These
spores germinate by means of one or two germ tubes. Some systematists consider the actinomycetes a connecting link between the bacteria and true fungi, but Drechsler disagrees (Rich, 1983).

Deeper pitted scab usually produces distinct brown; corky, sunken lesions of variable size, they are roughly circular, and the majority of them 1–5 mm in diameter. Thin–skinned red or white cultivars are usually susceptible (Rich, 1983).

Robert (1955) mentioned that common scab, ordinary scab, brown scab, potato scab, and scab are some of the names applied to what it is undoubtedly, the most common malady affecting Potato, as this scab is known wherever potato are cultivated. The earliest mention of the disease appears to be that in London Encyclopedia of agriculture in 1825, but the causal agent was not described until 1890 when Thaxter published his paper on it.

2.2.1 Taxonomy

Preferred name: *Streptomyces scabies*

Taxonomic position:

Class: Actinobacteria
Sub class: Actinobacteridae
Order: Actinomycetales
Sub order: Streptomycineae
Family: Streptomycetaceae (Thaxter 1892), (lambert & Loria, 1989)

2.2.2 Others Names used

*Oospora scabies* (Thaxter 1892).

*Actinomyces scabies* (Thaxter) Gussow, 1914).

**Streptomyces scabies** (exThaxter) Lambert & Loria, 1989)

### 2.2.3 Common Names

English: Potato scab, scab of potato and common scab

Spanish: Rona comun de lapapa, Actinomicosis-

\[ \text{delapatata} & \text{ sarna ordinaria de la patata} \]

Rona de laptata

French: 8 ale commune de la carotte – gale commune du navet – gale commune de la pommus dettere

Germany: Gewoehnlicher: kartoffel schorf. Kartoffetschorf (Thaxter, 1892)

### 2.2.4 Nomenclature

For many years any *Streptomyces* that caused potato scab was assumed to belong to this species. Because of this approach many taxonomically different isolates have been given the name *S.scabies* and found their way into culture collections. Thaxters original isolates were lost and in the absence of an acceptable type culture, the species was excluded from the approved list (Skerman et al., 1980) and had no standing in nomenclature. The name was subsequently revised by Lambert and Loria, (1989) and a new type strain proposed. The nomenclature was recently corrected by Truper and Declari, (1997) changing the epithet from the substantive noun (scabies - the potatoes scab) to its genitive form (scabiei – of potato scab).

### 2.2.5 Distribution

Walker (1957) mentioned that the disease is world-wide in occurrence. In highly acid soils it is relatively scarce, while in soil with moderate hydrogen-ion concentration and particularly in muck soils it is
most prevalent and most important. Table beet, sugar beet and radish are common economic hosts.

Common scab occurs most frequently on light, sandy, or gravelly soils, and it is most prevalent in dry seasons. It is rare on peaty and heavy soils (Brooks, 1928).

This disease should be considered wide spread in all of the major potato growing regions of the world (Loria et al., 1997).

Bacterial growth is favored by worm, moist conditions. Bacteria thrive on medium containing starches and sugars. Thus potato tubers are a good medium for their growth. Some bacteria attack only tubers, while others attack both tubers and plants (Rich, 1983).

Tarr (1955) reported that the distribution of any plant disease within the Sudan is governed largely by the presence or absence of suitable host plants and suitable climatic condition. However, other factors do undoubtedly play a part. Thus soil characteristics including PH composition, temperature and moisture content are important in root diseases.

2.2.6 The Economic Importance

The disease is widespread in all the potato growing regions of the world and reduces the marketability of table, processing and seed potatoes and was ranked as the fourth most important disease in a 1999 survey of potato growers (Loria et al., 1997). Due to the disease’s effect on marketability rather than yield, exact losses are difficult to quantify however some scattered data exist in the literature, in Bangladesh in 1969, yield losses of potato tuber in cold storage at 22 locations amounted to about 2.2 – 9.5 % of the total. Losses were caused by dry rot (Fusarium spp.), bacterial soft rot (Erwinia spp.), common scab (S. scabies) and physiological
disorders (khan et al., 1973), a similar story exists in Bosnia – Herceg, Ovina where virus disease and scab are particulary destructive (Buturovic, 1972). In a study on the effect of radish scab, the disease badly affected the market quality and caused losses of up to 100% in some cases from farmers in Barlin and Germany (Koronowski and Massfeller, 1972).

Several potato diseases can cause severe crop losses if not properly managed. These include early blight, late blight, scab, black leg, leafroll and mosaic viruses, rhizotonia, verticillum wilt, fusarium dry rot, and bacterial soft rot (Christ, 1998).

Western (1971) mentioned that common scab one of the few plant diseased caused by an *Actinomycetes*, affects underground parts, but primarily the potato tuber, where the usually superficial blemish decreases value rather than yield, sever root infection has been recorded as occasionally decreasing yield.

Walker (1957) reported that the great loss from scab is brought about by the blemish to the appearance of the tuber and the consequent reduction in commercial grade. Scabby potato lowering the market grade, mean an anual loss of several million dollars (Horst, 1969).

The influence of tuber infection is negligible in comparison to the infected soil. It only affects sprouting when the tuber is severly attacked. It is of minor importance but the physical appearance of the tuber is negatively influenced (Luitiens, 1986).

Wheeler (1972) noted common scab of potato caused by *S. scabies* unsightly pustules of the tubers reduce their market value and storage qualities. The pathogen is soil-borne.
Robert (1955) mentioned that common scab injurious in the following ways:

- Scabby potatoes are unsightly, and their appearance detracts from their market value.
- Deep Peeling of badly affected tubers is necessary previous to cooking and this leads to considerable waste.
- During storage, and especially under dry conditions scabbed tubers lose more moisture than clean tubers; this leads to shrinkage in storage and loss in weight.
- Scab lesions facilitate the entrance of secondary organisms which cause rot. In wet years this is particularly true of the blight fungus *Phytophthora infestans*.
- Badly scabbed tubers are unsuited for seed purposes. Apart altogether from spreading the disease, the eyes of such tubers are often weakened and, if they sprout at all, the sprouts are weak.

### 2.2.7 Host range

According to Chupped and Sherf (1960); Rich, (1983); Lambert (1991); Goyer and Beaulieu, (1997) scab occurs on fleshy roots or tubers of beets, cabbage, carrot, eggplant, mangel, onion, parsnip, radish, salsify, spinach, and turnip.

In addition, groundnut grown in rotation with potato have exhibited warn't – like lesions and *S. scabies* was consistently isolated (De klerk et al; 1997).
2.2.8 Biology and Ecology

Inoculation of aseptically cultured minitubers with cell–free extracts from scab lesions of field–grown and cultured tubers infected by *S. scabies* reproduced symptoms typical of the common scab disease (Lawrence et al., 1990). Isolation and fractionation of the active components yielded two active compounds, which were designated thaxtomin A and thaxtomin B. In further studies 23 isolates obtained from scab infected potato tubers were screened for pathogenicity (King et al., 1991). The results were then correlated with any associated generation of the scab–inducing phytotoxin, thaxtomin A. In all cases a positive correlation was demonstrated between the pathogenicity of various *S. scabies* isolates and their ability to produce the phytotoxin. These results were confirmed in subsequent study as a positive correlation between the pathogenicity of *S. scabies* isolates and the ability to produce thaxtomin A (Slabbert et al., 1994).

Kenneth (1969) reported that the pathogen can be found even in virgin soil. It invades young tubers and may sometimes be seen as a grayish coating on freshly dug potatoes. It is most destructive in soil with PH 5.7 and over, with its activity sharply limited in soils slightly more acid. Although its optimum temperature is 72 to 86 F°, the pathogen can withstand great extremes of temperature and moisture and can pass through the digestive tract of animals, returing to the field in manure.

2.2.9 Morphology

Shirling and Gottleib (1966) pointed out that the organism is aerobic, Gram–positive, producing highly branched, unfragmented mycelia. Colonies are slow growing and become velvety powdery with age, as aerial hyphae and spore masses develop. Spores (0.5 x 0.9 – 1.0 µ) are smooth, grey and
are brown on mature spiral spore chains containing 20 spores or more. Melanin is produced on tyrosine agar.

Aerial mycelium in pure culture consists of prostrate branched threads. Sporogenous hyphae are spiral in form. Spores are produced by the formation of septa at intervals along the hypha, which contract to form narrow thmuses between the cells. When the spores in the chain mature, final cleavage takes place. The spores are roughly cylindrical (0.6 to 0.7 by 1.0 to 2.0 µ) and hyaline. They germinate by means of one or two germ tubes (Walker, 1957).

2.2.10 Symptoms

Hooker (1981) noted that scab symptoms are quite variable and are localised on tuber. With no above–ground symptoms. Lesions are usually roughly circular, raised, tan to brown, corky in appearance and between 5 – 10 mm in diameter. The pathogen can induce erumpent, pitted or superficial lesions on tubers, with the former being considered the most common (Loria et al., 1997). Although scab symptoms are not usually noticed until late in the growing season or at harvest, tubers are infected during the period of rapid tuber growth that commences when the tuber diameter reaches twice that of stolon. Small brown water–soaked, circular lesions are visible on immature tubers associated with lenticels within a few weeks after infection (Lapwood, 1973). Janse (1988) mentioned that mature tubers with a well–developed skin are no longer susceptible, but existing lesions will continue to expand as tubers enlarge. Carrot scab was first recorded in the Netherlands during a dry growing season in 1986 and symptoms included deep, superficial and raised scab. Circular white lesions (0.5 – 1.5 cm diameter) can be found on radish with raised edges and sunken centers.
(Levick et al., 1985). On groundnuts, unusual pod symptoms have been observed, ranging from a net blotch with scattered lesions to dark brown, necrotic, wart-like lesions (De Klerk et al., 1997).

Walker (1957) mentioned that shallow and deep scab are two phases commonly referred to in popular and scientific literature. Shallow scab consists in a superficial roughened area, sometimes raised above, and often slightly below, the plane of the healthy skin. It consists of corky tissue which arises from abnormal proliferation of the cells of the periderm of the tuber resulting from invasion by the pathogen. The lesions vary widely in size and shape and usually, are slightly darker than, but not greatly different in color from, the healthy skin. This symptom may be such that it causes a diffuse russet, or it may grade into the deep phase.

Deep scab, or pitted scab, consists of lesions which are 1 to 3 or more mm deep. They may be darker than shallow lesions, The tissue around the interior of the pits is corky, as in shallow scab. Opinions differ as to the nature and origin of deep-scab lesions. One view is that certain physiologic races of the organism incite this type of lesion while other races incite shallow scab. Another view is that deep scab is the result of combined action of the scab organism and of chewing insects attracted to the incipient lesions (Walker, 1957).

2.2.11 Disease Cycle

Walker (1957) reported that the pathogen may subsist indefinitely in favorable soil. It is distributed chiefly on infected seed tubers, wind, water and soil. It may survive passage through the digestive tract of animals and become distributed with manure.
The young tuber is most susceptible to infection (Fellows, 1926). Penetration has been reported to occur through lenticles, stomata, wounds, and directly through the cuticle when the latter is very thin. As to relation of pathogen to host tissue after penetration, there is lack of general agreement (Walker, 1957). Lutman (1913) reported that the filaments progressed intercellularly at first, apparently digesting the middle lamella. Hooker et al (1950) described that the filaments as interacellular in potato stems. Cooper et al (1954) found that in young tubers of susceptible varieties several layers of dead cells are to be found on the exterior in which the fungus develops as a saprophyte. Underlying live cells probably as a response to metabolism of the organism, are stimulated to abnormally rapid division and consequent sloughing of more dead cells on which the pathogen continues to subsist. There appears to be little invasion of living tissue, but the scab lesion results from proliferation of the latter. By contrast, in resistant tubers few dead cells occur at the surface and the organism deprived of this substrate, fails to gain a foot hold while the tubers remain free, or relatively free of lesions. The larva of soil insects are common invaders of scab lesions and are responsible, in part at least, for the formation of deep lesions. Hooker and Sass (1952) found stem lesion generally more severe on susceptible than on resistant varieties in the greenhouse, but this difference did not occur in the field.

Various soil factors influence the severity of the disease, one of these which has received much study is soil reaction (Walker, 1957). Gillespie (1918) pointed out that growth of the organism was inhibited by high acidity – Numerous experiments have shown that the extent of infection is reduced quite rapidly as the PH decreases below about 5.2. There is some evidence
that above PH 8.0, infection is also inhibited. Within the range PH 5.2 to 8 the severity of the disease increases with increase in PH. Horsfall et al (1954) found correlation between the amount of scab and the calcium content of the tuber, but the manner in which calcium influences the disease was not determined. Waksman (1922) pointed out that some isolates of the pathogen grew in culture as low as PH 4.8. It is rather generally accepted that when potato soils are kept at PH 5.0 to 5.2, the disease is usually under commercially, satisfactory control.

Shapavlov (1943) found that the spores germinated most rapidly at 35 °C to 40 °C., while the cardinal temperatures for growth were maximum 40.5 °C, optimum 25 °C to 30 °C, minimum 5 °C. Jones et al (1922) in a study of the relation of soil temperature to disease development found the range to be between 11 °C and 30.5 °C with an optimum at about 20 °C to 22 °C. Sanford (1923) noted that increase in soil moisture tended, to reduce scab, and this was confirmed by Martin (1923). Dippenaar (1934) studied the relations of temperature, moisture, and soil reaction on scab development. He found the optimum temperature for infection to be slightly below 20 °C and that for lesion enlargement to be slightly above 20 °C. He also found that scab decreased with increase in soil moisture. Goss (1934) emphasized the importance of this soil factor and aeration in their effect on the soil flora for a period before infection. In some experiments the largest amount of scab occurred in soil held at high moisture content for some months before infection depressed the disease more than poor aeration provided during the post infection period. Starr et al (1943) in a study of the effect of different irrigation schedules on incidence of scab, found most
disease in the schedules which gave the highest total water supply and the least variation of soil moisture.

The reduction of scab by certain rotation schedules has been noted by some workers. Millard and Taylor (1926) in England emphasized the value of green manure as scab depressant. Also they agreed with Sanford (1926), in the opinion that the pathogen was inhibited by the activity of competitive organisms. Goss and Afanasiev (1938) compared the effects of rotations on scab under irrigation in western Nebraska. They found that 4 or 6 year rotations with alfalfa were most satisfactory.

It appears at present that soil reaction and soil moisture are the most influential factors on seasonal and regional incidence of scab. But it is equally apparent that the interaction of these with other less clearly defined factors make too rigid generalization unwise. By and large, scab remains an important disease because clear cut, workable, reliable, soil management procedures are not yet defined (Walker, 1957).

2.2.12 Pathogenicity

Millard and Burr (1926) noted variability in pathogenicity of strains of the scab pathogen. They set up several new species and believed that some caused shallow and others deep scab. De Bruyn (1939), in Holland was inclined to the same view. Afanasiev (1937), in Nebraska, was of the opinion that the production of shallow, russet, and deep scab was a function of the degree of virulence rather than of type of pathogenicity. Leach et al (1939) described two physiologic races on the basis of reaction to a seedling and to the resistant variety Jubele. The seedling was very susceptible to race 1 and highly resistant to race 2, while Jubele was only moderately susceptible to race 1 and highly resistant to race 2. Schaal (1944) showed
that most isolates are unstable in pure culture, variants being produced frequently which differ in physiology, morphology and pathogenicity. This was confirmed by the work of Thomas (Walker, 1957). Taylor and Decker (1947) reported a close correlation, in 143 isolates studied, between pathogenicity and formation of a dark brown ring of surface growth on milk. It is obvious that the scab pathogen is an exceedingly variable organism.

Houghland (1954) mentioned that common scab can be particularly severe in soils that are about neutral (PH 6.8 – 7.0) or slightly alkaline (PH 7.2 or higher), but it generally causes little if any damage in acid soils below PH 5.2. Applications of fresh manure, especially chicken or horse manure, should not be made just before the field is plowed for potatoes, because these manures favor scab development. Likewise heavy applications of lime or wood ashes tend to induce a soil reaction favoring scab development.

Ordinarily, common scab development is favored when the soil moisture is slightly below the requirement for optimum growth of the potato plant. If the texture of the soil promotes abundant aeration, however, scab may develop readily, even though the soil is very wet. The common scab organism is carried from one season to another in the soil and in the scabby spots on the tubers.

Robert (1955) reported that scab infection frequently starts at the lenticels of the young tuber. The first symptom of the disease is the development of minute reddish or brown spots. These increase in size and their colour becomes dark brown. In the host the invading organism stimulates the meristem to give rise to elongated cells and to form a cork barrier. This cork barrier, however is seldom perfect, and the organism manages to penetrate through it and invade the deep tissue. The subsequent
stimulation set up there leads to the formation of another cork layer. This in turn is passed and the stimulation of the meristem resumed, and the development of successive layers of cork in this manner leads to the enlargement of the scab. Meanwhile the cells cut off by cork layers collapse, accumulate in the lesion, forming a thick layer of dead tissue above the cork, and giving the pitted or sunken scab. Sometimes in common scab there is a general scruffiness and browning of the tuber surface, which results from a mass infection of the periderm.

The causative organism is capable of living in the soil for many years and also lives from year to year into the scabby spot on tubers (Thompson and Kelly, 1957).

2.2.13 Epidemiology

Walker (1969) pointed that the pathogen survives indefinitely in infested soil, spreading from one location to another primarily by infected seed tubers. It is also disseminated by infested soil which may be transported by wind, water, or mechanically. The organism may also be spread by contaminated manure after passing through the digestive tract of animals.

Some research workers have identified pathogenic strains of the scab pathogen (Millard and Burr, 1926) others believe that more than one species of Streptomyces is involved. Harrison (1962) blames an unnamed species of Streptomyces as the incitant of russet scab in Minnesota. Mecrum and Manzer (1967) demonstrated serological differences between species of Streptomyces.

S. scabies usually thrives best in soils with a PH range of 5.5 to 7.5 and rarely has been a problem when soils were maintained at a PH of 5.0 to 5.3. However, in recent years scab has become prevalent and severe in
certain soils with a PH below 5.0, giving rise to the names (“uncommon scab” and “acid scab”) to differentiate it from so-called common scab.

In Washington, land freshly cleared from sagebrush produced scab-free potatoes. However, after continuous cropping to potatoes for three years or more, scab became a serious problem (Rich, 1983).

2.2.14 Varietal Susceptibility

Walker (1957) mentioned that for a long time it has been known that varieties differ in their susceptibility to scab. In some strains in which tubers have russeted skin, fewer lesions appear than in smooth strains of the same variety, e.g., Russent Rural, Russet Burbank, and Russet Sebago. There is reason to believe, however, that the apparent resistance is not due to a smaller number of infections but to the fact that the reaction of the cells near the surface is more limited and the lesions are thus of less consequence. Some varieties developed in Germany and other European countries, e.g., Jubeel, Hindenburg, Ostragis, and Arnica, are very highly resistant. They are of no value in American potato culture as such but have been used widely as parents by potato breeders. Scab—resistant introductions derived from those parents include Menomines, Ontario, Seneca, Cayuga, Pungo, Cherokee, Osage, Yampa, and Antigo.

Longree (1931) found a correlation of resistance with degree of suberization of the lenticel meristem and with a tendency of the maturing tuber to slough the lesion. Darling (1937) found the lenticels of susceptible seedlings larger and made up of rounder and more loosely arranged cells than those of resistant seedlings, while the periderm of the latter suberized earlier and the suberization extended farther into the lenticel. Schaal et al (1953, 1955) attributed resistance to the greater amount of chlorogenic acid.
in the outer cells of the periderm of the tubers. Cooper et al (1954) believe that resistance is associated with pourcity of dead cells at the periphery on which the scab organism can establish itself.

Clark et al (1936, 1938) found varieties, e.g., Green Mountain, to breed true for susceptibility while Hindenbura and Ostragis were apparently homozygous for resistance. The susceptible variety Katahdin carries at least one gene for resistance in a heterozygous condition. Russetting was found to be linked genetically with resistance. Stevenson et al (1942) tested 22 varieties in scab gardens in Maine, Muchigan, Minnesota, and Colorado during two successive seasons and found the resistance and susceptibilty reactions to be fairly constant, indicating that variability in the pathogen would not seriously hamper the development of resistant varieties.

2.2.15 Detection and Inspection Methods:-

Loria et al (1995) pointed that no direct methods of detection appear in the literature, largely because spores of the pathogen exist widely in soil and symptoms are readily visible on tubers. Indirect methods do exist however and a tuber slice bioassay has been developed to detect thaxtomin A which is thought to play a major role in the expression of symptoms on potato and other susceptible root crops. Care should be taken however in the use of such a method, as other pathogenic streptomycetes also produce thaxtomins.

Conn et al (1998) reported that a related procedure for estimating streptomycetes population in soil is reliant on the use of a semi-selective culture medium prior to screening for thaxtomin production, by extraction from the growth media followed by detection by miniature thin layer
chromatography. Using this method it was possible to identify strains of *S. scabies* and *S. acidiscabies* which did not produce aerial mycelia or sporulate, an important characteristic in species determination. Using these procedures, the population – of the thaxtomin – producing *S. scabies* in soil from a potato field in Ontario, Canada, with history of potato scab was estimated at (~20,000 C. F. U/g), soil.

### 2.2.16 Diagnostic Methods

Lambert and Loria (1989) explained that *S. scabies* can be distinguished from other scab causing *Streptomycetes* by their use of raffinose as a sole carbon source, production of melanin, in ability to degrade xanthine and grow below PH 5, and susceptibility to streptomycin and crystal violet.

Using DNA hybridization techniques the distinctiveness of *S. scabies* strains from other scab forming *Streptomycetes* was confirmed, through a high degree of diversity that exists within the species (Healy and Lambert, 1991). These findings were confirmed by (Paradis et al., 1994), studying fatty acid composition, protein profiling and DNA – DNA hybridization of 31 pathogenic and non pathogenic strains from potato. They found that *S. scabies* strains, whilst highly diverse, could be distinguished from other pathogenic *Streptomycetes*.

### 2.3 Control of the Disease

Walker (1957) reported that treatment of potato seed tubers for control of scab was initiated by Bollay in North Dakota in 1891.

#### 2.3.1 Cultural practices

Although complete control cannot be achieved, disease severity can be managed by cultural practices. The maintenance of high soil moisture can
achieve adequate control of potato scab (Davis et al. 1974; Davis et al. 1976; Adams et al., 1987; Lordia et al., 1997), especially when applied early in the season (Barnes, 1972; Lapwood et al., 1973).

Experiments conducted in the UK and Netherlands showed that irrigation greatly reduced the damage caused by scab on carrot (Groves and Bailey, 1994; Schoneveld, 1994). Maintaining a low soil pH, can also reduce scab through the application of elemental sulfur, gypsum (Davis et al., 1974), or acid forming nitrogen fertilizer, such as ammonium sulfate (Mizuno et al; 1995).

Scab resistance is an objective of most breeding programmes, though no completely resistant cultivars exist (Mckee, 1958; Goth et al., 1993), and can be attributed to a poor understanding of possible resistance mechanisms (Loria et al., 1997).

2.3.1.1 Use of irrigation

Sanford et al (1923) mentioned that wet soil has long been known to inhabit potato common scab *S. scabies*. Lapwood (1968) and Hering (1970) confirmed a recent work which shows that scab is most severe when the soil is dry soon after tubers begin to develop. Irrigation in 1970 at Gleadthorpe increased potato yields, and when given from the time of tuber initiation, controlled common scab on the susceptible cultivars king Edward, Majestic and Record. Pantland grown had little scab with or without irrigation. It was the driest May and June since 1934 and there was already a soil moisture deficit (S. M. D.) of 1.8 in (46mm) at tuber initiation by king Edward and when water was first given. Subsequently irrigation at 0.6 in. (15mm) or 0.8 in .(20 mm) S.M.D. was more effective than 1.5 in (38mm) or 2.25 in (57mm) S.M.D in controlling scab, and more effective at 0.6 in
S.M.D when maintained for 4 weeks than for 2 weeks. Tubers developed slowly in unirrigated plots both in volume and in the rate that eyes separated. King Edward produced more tubers per plant than Majestic, irrigation did not increase tuber number (Lapwood et al., 1971).

Western (1971) pointed out that supplementing rainfall by irrigation where practicable to keep the soil moist for perhaps 4-6 weeks after tuber initiation seems a promising way to control scab even on the most affected land.

Soil population of *S. scabies* are difficult to study because there is no quick and reliable method for identification. However, examining crops shows that scabbing very greatly with local soil differences even within a single field, liming or alkaline soil increases the disease, whereas watering soil decreases it. In wet soils bacteria increase in number, and although the frequency of all *actinomycetes* remains very much the same, fewer *S. scabies* are isolated than from dry soil. The disease develops at soil temperatures between 13 °C and 25 °C with an optimum (determined by lesion number) about 20 °C, less soil moisture is necessary to check scab at 13 °C or 25 °C than that at 20 °C. Previous crops, and management factors such as liming for barley, adding green manures, ploughing pasture *S. scabies* as a normal inhabitant of grass roots, frequency of growing potatoes and the susceptibility of the varieties grown may affect soil populations and scab incidence.

Weinhold et al (1964) mentioned that ploughing in soybean, as a green manure crop, before planting potatoes has been effective in the U.S but not where the population of *S. scabies* is large.
Scab is generally favored by low soil moisture. Thus irrigation has been suggested as a means of control (Divs et al. 1972; Mckee, 1968).

Kenneth (1969) mentioned that alkaline materials—lime, woodashes, and manure—should not be applied to potato soil. Thompson and Kelly (1957) reported that the scab organism is not active at soil reaction below PH 5.4 or above PH 7.6, hence it could be controlled by maintaining the soil reaction at PH 4.8 – 5.2. Scab is severing in dry than in wet season, also in worm than in cool season.

### 2.3.1.2 Use of fertilization

Vanloon and Houwing (1989) mentioned that in integrated farming the amounts of N, P and K applied should be adjusted to meet needs revealed by soil or tissue analysis. It is better to use organic manure rather than artificial fertilizer, provided that the losses of \( \text{NO}_3 \) and \( \text{NH}_3 \) to the environment can be minimized. The advantages of organic manure are, its relative cheapness, its beneficial effect on soil structure, its stimulating effect on soil fauna, and the extra yield increase that cannot be reached by artificial fertilizer. Organic manure is best applied in spring when the leaching of nitrate is minimum. Farmers can get on to sandy soils at that time of the year, but on the wetter clay soils this is more difficult. A disadvantage of organic manure is that it does not allow precise fertilization with N, since the proportion of the organically bound N that mineralizes during the growing season cannot be predicted. This may lead to shortage or excess of N in the crop. This problem can partly be overcome by a split application of N, provided the second application is based on the nitrogen status of the plant or the soil. Petiole nitrate content has proved to be a useful indicator of the crop nitrogen status. Doll et al. (1971) reported
that regular soil analysis of mineral N during the growing season may lead to a comparable result. Neeteson (1989) pointed that the present nitrogen recommendations for potatoes in the Netherlands result in too much nitrate in the surface water in the autumn and winter after the potatoes have been grown. This is because of the inefficient use the crop makes of the available N. Only 34-40% of applied fertilizer N is recovered by the potato tubers. The remainder may leach out during winter, unless a green manure crop is sown after harvest, to fix a part of the nitrate. On light soils such a catch crop may also protect the soil against wind or water erosion.

If current nitrogen recommendations for an optimum tuber yield are cut by about 15% the nitrate content of surface and drinking water will not exceed the admissible level of 50 ppm. Such a reduction of the nitrogen rate will reduce the net returns of the potato crop by only 2% (Neeteson, 1989).

Vanloon (1989) mentioned that an additional advantage of such a reduction is that a number of quality characteristics of ware potatoes can be improved, and that crops develop less foliage which may reduce their susceptibility to late blight. A moderate application of nitrogen in seed potatoes will enhance maturity–resistance to virus diseases (Beemster, 1987).

2.3.1.3 Resistant varieties

Walker (1957) reported that resistant varieties are the ultimate solution for control of this disease. The tolerant varieties are useful in this regard, but they are not successful under conditions extremely favorable for scab.

Hasson (1999) pointed that the resistance occurs on a big number of russetted skin varieties. Pentland crown is more resistant than Majestic, but
there is no acceptable replacement for king Edward (Western, 1971). Somewhat resistant varieties include Menonimee, Ontario, Cayuga and Seneca (Kenneth, 1969).

2.3.1.4 Crop rotation

Bollen et al (1989) found that when cropped once every six years potatoes yield 7% less than a first cropping with potatoes, and when grown once every three years this reduction can be as much as 20%. Soil borne diseases such as *Verticillium dahliae*, *R. solani* and *S. spp* appeared to be the main organisms responsible for the decline in yields.

2.3.1.5 Soil cultivation

Specht (1985) reported that in integrated farming, soil cultivation should be directed to improving soil structure and controlling weeds, while using the minimum of energy.

2.3.1.6 Biological control

Field studies on the biological control of potato scab using a non–antibiotic producing *Actinomycete* biofertilizer reduced scab severity from 10.7 to 2.3% (Nanri et al., 1992). Lesions were slight and potato production was three times higher in the biofertilizer subplot than in the control subplot. Viable counts of *S. scabies* in the biofertilizer subplot decreased whilst antagonistic fluorescent *Pseudomonas* were found to increase. Further studies have demonstrated control of potato scab by two suppressive strains of *Sreptomyces S. diastatochromogenes* strain ponssII and *S. scabies* strain pon R in a 4 year field – pot experiment (Liu et al., 1995). Both strains significantly decreased scab on potato tubers of potato cv. Norchip compared with the nonamended control treatment. The supressive strain did not affect tuber yield and were re-isolated from the tubers over the 4 years of
the experiment. Subsequently, the antibiotic produced by ponssII was found to only inhibit pathogenic strains of \textit{S. scabies}, but not a range of other bacteria commonly found in soil (Eckwall and Schottel, 1997). In further experiments 93 \textit{streptomycetes} were isolated from lenticels of potato tubers grown in naturally disease-suppressive and disease-conductive soils (Liu et al., 1996). Of these 22 strains showed greater antibiotic activity against virulent \textit{S. scabies}, RB 311 than pon R and pon ss II. These strains were non-pathogenic on leaf–bud tubers in greenhouse testing and significantly reduced scab without affecting tuber yield in field-pots tests. Other bioactive compounds have also been studied as possible control agents, antibiotic substances from a red alga, \textit{Laurencia okamurae} (Horikawa et al., 1996).

\subsection*{2.3.2 Control with Natural “Pesticide” The Neem Tree (\textit{Azadirachta indica}) (A. Juss)}

\subsubsection*{2.3.2.1 Classification}

Ladd et al (1978) reported that the Neem Tree \textit{Azadirachta indica} (A. Juss.) is member of the \textit{Meliaceae} family. Formerly known as \textit{Melia azadirachta} (Linn.) or \textit{Melia indica}.

Radwanski (1977) pointed that the Neem tree is an evergreen which takes 10-15 years to become full grown at a height between 12-18 meters. The Neem tree does not produce fruit throughout the whole year.

\subsubsection*{2.3.2.2 Distribution}

Jacobson (1977) mentioned it is cultivated all over India and Burma and it introduce to Africa during the last century. It is now well-established in a number of African countries particularly in the rainfall deficient regions such as the Sahel zone. The Neem tree is now found in Cameroon, Nigeria,
Gambia, India, Burma, Pakistan, Japan and some other countries of Africa and central America.

2.3.2.3 Chemistry of Neem

More than 100 compounds have been isolated from the various parts of the Neem tree e.g. The seeds, the seed kernel and bark Azadirachta and its relatives are the most biologically active compounds of Neem followed by less biologically active groups such as degunin, vepinin, vilasinin, nimbin and salanin (Jonesel, 1989; Schmutterer, 1995).

2.3.2.4 Neem’s effectiveness

Neem products have been tested on 133 species of insects, 3 species of mites, 8 species of nematodes and 6 species of fungi (Ketkar, 1976).

Singh and Kataria (1985) reported that plants elaborate various types of chemicals to defend themselves against insect and other organisms.

In Sudan Siddig (1987) reported that Neem seeds and leaves water extracts at 1 Kg/40 liter of water repelled foliage pests of potato and increased yield.

Satti (1991) reported that the Neem seeds water extract was found comparable to the standard insecticide Malathion in controlling cucumber pests.

The Neem seeds water extract was recommended as one of components of integrated pest management (IPM) suggested for control of some potato pests (Siddig, 1993).

Neem seed water extract and organic extracts efficiently controlled powdery mildew on cucumber as shown by trials executed by Mukhtar (1997).
2.3.2.5 Neem research in the Sudan

Siddig (1991) mentioned that research work in Sudan back date to the year 1967. When the author started some observation trials at Hudeiba Research station. These trials evaluated different parts of the neem tree as protectants to wheat against the store pest *Trogoderma granarium* Evers. Preliminary results were encouraging to resume this type of research later on at Shmbat research station.

2.3.2.6 Neem advantages

Prajapati (1998) reported that Neem Biopesticide (Emulsifiable Concentrate) is well suited for an Integrated Pest Management (IMP) Program because of the following salient features

- Neem Pesticide is a natural product, absolutely non toxic, 100\% biodegradable and environmentally friendly.
- It is suited for mixing with other synthetic Pesticides and in fact enhances their action,
- None or lesser quantity of synthetic pesticides need to be used, thereby reducing the environmental load.
- Several synthetic pesticides being single chemical compounds cause easy development of resistant species of pests. Neem consists of several compounds hence development of resistance is impossible.
- Neem does not destroy natural predators and parasites of pests thereby allowing these natural enemies to keep a check on the pest population.
- Neem also has systemic action and seedlings can absorb and accumulate the neem compounds to make the whole plant pest resistant.
- Neem has a broad spectrum of action active on more than 200 species of pests.
• Neem is harmless to non-target and beneficial organisms like pollinators, honey bees, mammals and other vertebrates.

2.3.3 Chemical control

Kenneth (1969) mentioned that seed tubers have been treated with formalin, but the organism is so prevalent in potato soils that such treatment may have little result. Soils already slightly acid may be further acidified with sulfur, from 300 to 2000 Pounds per Acre. Enough sulfur to acidify highly alkaline soil would be too expensive and too injurious to Potatoes. Treating soil with Terraclor or vapam before planting has increased yield of marketable potatoes.

Walker (1957) pointed out that formaldehyde and mercuric chloride have been used extensively. The original formula usually recommended were 1-1000, mercuric chloride soak for 1.5 to 2 hours, or formaldehyde (40 per cent solution) 1-240 soak for 2 hours. In order to shorten the period of treatment, the hot formaldehyde treatment (1-120 at 50 °C, min) and the acid- mercury dip (1-1000 mercuric chloride plus 1 per cent hydrochloric acid 5min.) were devised. While tuber treatment is effective in reducing or eliminating introduction of inoculum, the organism has become so widely prevalent in many commercial potato soils that the benefit of tuber treatment is often of doubtful value.

Weinhold et al (1964) obtained soil treatment with chemicals including urea acides, urea formaldehyde, manganese sulphate, Pentacholoro nitro benzene (P.C. N. B.), or quintozen have been variously successful, as sometimes has acidifying a soil to a round PH 5.2 with sulphur.
2.4 Cultural methods for pest control in the Sudan

Mohammed (1985) reported that history of agricultural operations is as old as the agriculture itself. It was practiced in a time when insecticides were not known. The success of these operations led to the emergence of laws and legislation for protecting and insuring the implementation of agricultural operations. The year 1935 witnessed the emergence of the legislation for the operations of cleaning cotton fields from the crop remains.

2.4.1 Indicatives samples for control through husbandry practices

The means of agricultural control, such as despoing crop remains, choosing the suitable sowing date and using premature strains of cotton have been a useful way for stopping the spread of the boll weevil in America. Also the late cultivated maize in Northern and centrial America least spread of the European corn borer. Since the stem borer stay inside the crop’s remains all winter, so they would be destroyed through the removal of these remains before the time of cultivation.

Also in Egypt, it was found that ploughing of *Medicago sativa* in fields twice intersecting on preparing for cultivations cotton, protected the first from larva of the cotton leaf worm (Mohammed, 1985).

2.4.2 Some of husbandry practices, successfull in the Sudan

2.4.2.1 Control of irrigation

In Zedab project the green worm has been totally eliminated in the year 1935 through shortening the time of growth by decreasing irrigation periods (light irrigation). This treatment increase the growth of cotton and win the danger stage for the worm (Mohammed, 1985).
2.4.2.2 Uprooting, stem removal and clearance:

The removal of crop remains and burn after picking is a fundamental agricultural operations in cotton fields for controlling Pests. It was legally practiced in the irrigated projects since mid thirties of the nineteenth century. And this operation aims at eliminating and stopping the spreading of pink boll worm, black arm disease and leaf curl virus disease (Mohammed, 1985).

2.4.2.3 Sowing date and harvesting

Early cultivation of cotton before or in the first of July in the Gezira project and middle rained areas increases the infestation of *Thrips tabaciL*, *Podagrica puncicolis* and *leaf curl virus* disease, but it decreases the infestation of (Pink boll worm) *plateyedra gossypiella*. Late cultivation (mid of August) eliminated infection of black arm disease (Mohammed, 1985).

2.4.3 Some methods of control applied in the Sudan

- Land ploughing and hoeing.
- Sticking to the suitable dates for cultivating and harvesting.
- Selecting healthy seeds.
- Selecting a suitable variety of crop for each certain area.
- Sticking to a suitable agricultural rotation.
- Methods of cultivation.
- Thinning & pruning.
- leaving land fallow (uncultivated).
- General clearance, getting rid of infection sources, alternative hosts and crop remains.
- Close or dead season.
• Caring of irrigation and drainage.
• Caring of fertilization operations.
• Using some plants as traps.
• Using resistant plants.
• Making use of density planting. (Mohammed, 1985).
CHAPTER THREE
MATERIALS AND METHODS

3.1 Field Experiment:

A field experiment was conducted in two consecutive winter seasons namely 2002 and 2003 at Shihanab region (60 km North of Khartoum State) to study the effect of some cultural practices (irrigation and fertilization) on the performance of four varieties of potato under contaminated soil condition with common scab of potato (*Streptomyces scabies*).

3.1.1 Experimental land:

Firstly the soil of the experiment was cleaned from the previous crop and then ploughed by using disc blow, then leveled by using scrapper and finally ridging by using ridger. After that the area was divided into 32 Plots (as an experimental unit) according to the number of treatments and replications. The size of each plot was 20 m² (5m × 4m) containing 5 ridges (70 cm between ridges). Then left for two weeks to be exposed to sun light. The nature of the soil is light clay about 300 m far from River Nile.

3.1.2 Treatments and Experimental design:

Four introduced varieties of potato (1st generation) were used in the present study, three of which were used under contaminated condition with common scab of potato (*Streptomyces scabies*) and one as a control. These varieties namely Alpha, Draga and Diamond in addition to Alpha (the same variety) as a control, latter on designated as V₁, V₂, V₃ and V₄, respectively. Also two cultural practices were used in this study as a combination, which were irrigation and fertilization. Two irrigation intervals were applied to
create a variation in the quantity of irrigated water. These intervals were every 6 days (short watering interval) and 8 days (long watering interval) and every irrigation interval was to be according to field capacity. On the other hand, N in form of urea was used in the present study. Two levels of N fertilizer were used, 130.4 kg N/fed (heavy dose) and 86.9 kg N/fed (low dose). The first level (130.4 kg N/fed) was split into three equal doses according to the stages of plant growth. The first dose was given at sowing date, whereas the second and third doses were given at burying and at tuber formation stages, respectively. Mean while, the second level of nitrogen (86.9 kg N/fed) was split into only two equal doses. The first dose was given at sowing and the second dose at burying. Method of nitrogen application was broad casting. It is to be that the higher nitrogen level (130.4 kg N/fed) was associated with the shorter irrigation interval (every 6 days) as one treatment, whereas the lower nitrogen level (86.9 kg N/fed) was associated with the longer irrigation interval (every 8 days). Then every treatment was replicated four times and accordingly the experimental units of this work was 32 subplots (4×4×2). The randomized complete block design in factorial experiment (FRCBD) was used to lay out the experiment and analyse the collected data. Mean while, Duncan's method {Duncan's New Multible Range Test (DNMRT)} was used to separate treatments means.

The experiment was conducted on the first week of December 2002 and 2003, respectively. Tubers after ventilating in a week were longitudinally sectioned using sterilized knives, each section or piece contained one or two viable buds. Then pieces were directly sown 20 cm
between holes in the Northern side of the ridge. Weeding was done three times, in the 2nd, 4th and 6th week from sowing. Also burying was done during the 7th week from sowing to prevent tubers greening which occurs as a result of exposure to sunlight.

### 3.1.3 Soil contamination:

The causative organism of common scab of potato is *Streptomyces scabies*. The organism was isolated in the laboratory from infected Potato tubers by the following steps,

- Selecting of potato tubers which showed the symptoms of *S. scabies*.
- Preparing of PDA medium.
- Scratch part of the lesion in distilled water, then put it in ethyl alcohol for a minute then prepare water suspension of the causative organism.
- Take a drop of the suspension using a Loop and culture it in PDA media in Petri dishes.
- Then the isolated causative organism was cultured in PDA medium at 37°C for 15 days. After that the cultured organism was mixed by using blender and then diluted at a ratio of 78.8 liter/fed, (0.4 liter/plot). The density of the organism in the suspension was $7.8 \times 10^8$ CFU/ml.

The suspension was then transferred from the lab to the field after eleven weeks from sowing and spreaded closely near the stems of the plants to insure the existence of the organism in the soil near the plants.

### 3.1.4 Pathogenicity test:

This test was done according to Khoch’s postulates methods (susceptibility and pathological effects) to identify and insure that the causative organism in the field experiment was exactly common scab
organism (*Streptomyces scabies*). Infected tubers for each variety under the study were collected after 12th week from sowing by digging at 20 – 30 cm depth. The organism was then isolated in the lab. (as previously mentioned steps) and stained for identification. The isolate was then identified through its shape which looks like tree structured shape (Shirling and Gottlib 1966). After that the isolate was cultured in PDA medium at 37°C. After 15 days the cultured isolate was transformed to the field and inoculated into healthy tubers by using a loop after digging the soil and labeling plants under the study. After 14th week from sowing, the labeled plants were dug and examined to confirm the presence of the causative organism.

3.1.5 The studied parameters:

After maturity (110 days from sowing), tubers from each treatment were carefully harvested manually using hand hoe. Then the harvested tubers from each treatment were weighed as bulk to obtain yield per unit area. Then harvested tubers were classified into infected and healthy tubers. The infected tubers from each treatment were then weighed and classified into three categories according to their size large, medium and small. Each category was further classified into three categories namely high medium and low infection, this process was applied so as to check the intensity of infection and done according to the infected lesions area of tubers, so the tubers which have more than 5 of symptoms regarded as high infection, from 3 – 5 medium infection and less than 3 were low infection. Also the three categories were weighed to obtain the percentage of infection for each category in relation to the whole infected tubers. Then the data collected from the above mentioned categories were subjected to statistical analysis using the previously mentioned design to study the performance of potato
varieties grown under contaminated conditions, the application of irrigation and fertilization and their interaction on these parameters.

3.2 **Laboratory Experiment:**

A laboratory experiment was conducted during July 2004 to study the effect of neem seed extract at different concentrations on the inhibition (suppression) of *Streptomyces scabies* growth with time. Neem extract was prepared as follows:

- Collect fully mature Neem seeds from Shambat area (U of K faculty of Agriculture) in June 2004 (shaking and selecting).
- Cleaning the seeds thoroughly.
- Soaking the seeds in cool water for 24 hours to reject the external layer.
- Drying the seeds under shade condition for one week.
- Remove the hard layer that covers the kernel by using mortar to obtain kernels.
- Drying the kernels under shade condition for a week using papers.
- Crushing the kernels by using blender to obtain the content of kernel in form of powder.
- 20 gm of the powder was then suspended in 200 ml of distilled water for 48 hour and filtered to obtain neem extract.

Three concentrations from neem seeds extract in addition to control were used to determine their ability to inhibit the growth of *Streptomyces scabies* cultured in Petri dishes adoptivs the same method mentioned previously for preparing the causative organism for the field experiment. These concentrations were 10 %, 5 % and 2.5 % ml of neem seed extraction added in 90, 95 and 97.5 ml of distilled water respectively.
From the suspension, about 5 full loop of cultured *Streptomyces scabies*, were then transferred into sterilized and equal size Petri dishes (9 cm diameter) and then well distributed throughout the whole bottom area of the Petri dish with PDA medium to insure even distribution of the pathogen. Immediately 5 drops from the diluted neem seed extract from each concentration (10 %, 5 % and 2.5 %) were then added to the experimental units (Petri dishes) using a pipette in addition to the control. For each treatment three replications were used. Then number of *S. scabies* colonies in the testing area were counted after the first, second and third week from application so as to study the effect of the different concentrations of neem seed on the *S. scabies* growth with time. The collected data from the experimental units were subjected to statistical analysis using the factorial completely randomized design ($3 \times 4 \times 3$). Separations between treatments means (Neem seed concentrations, time of applications and their interactions) were done by using Duncan's New Multiple Range Test.

3.3 Study of factors associated with economic losses due to common scab infection:

For this purpose a questionnaire was designed and distributed to potato growers in the area under the study (appendix 6). In this questionnaire 15 factors associated with the economic losses were mentioned to estimate the correlation between these factors and the economic losses due to infection by the disease which affects the tuber quality (consumer taste).
4.1 Field Experiment:

4.1.1. Rate of general infection:

In both seasons short watering interval and increased fertilizer application, varieties and their interaction significantly (p<0.01) affected the rate of general infection (appendices 4 and 5).

Application of short watering interval and fertilization in both seasons had a significantly higher percentage of general infection rate as compared to long watering interval and fertilization (table 1). In the first season V₃ recorded a significantly higher percentage of general infection rate as compared to all other varieties, whereas V₁ had a significantly lower percentage of general infection rate compared to all other varieties (table1). On the other hand, V₄ recorded a significantly higher percentage of this character compared to V₂ (table 1). In the second season, both V₂ and V₄ recorded a significantly higher percentage of general infection rate as compared to both V₁ and V₃, which they were not significantly different from each other (table 2).

The interaction between short watering interval and fertilization and V₃ gave a significantly higher percentage of general infection rate at all occasions in the first season, whereas, short watering interval and fertilization XV₁ interaction resulted in a significantly lower percentage of this character at all occasions in comparison to all other interactions(table 1).
Table (1): Effect of irrigation and feratilization on percent tuber infection incidence.

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<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
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<tr>
<td>Heavy irrgation &amp; fertilization</td>
<td>(16.0)</td>
<td>(26.6)</td>
<td>(39.3)</td>
<td>(35.8)</td>
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<td></td>
<td>f</td>
<td>cd</td>
<td>a</td>
<td>ab</td>
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<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(19.2)</td>
<td>(22.1)</td>
<td>(31.9)</td>
<td>(24.2)</td>
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<tr>
<td></td>
<td>ef</td>
<td>de</td>
<td>bc</td>
<td>de</td>
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<tr>
<td>Var.mean</td>
<td>(17.6)</td>
<td>(24.4)</td>
<td>(35.6)</td>
<td>(30.0)</td>
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<td></td>
<td>d</td>
<td>c</td>
<td>a</td>
<td>b</td>
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S.E ± for irrig. And fert. (A) 0.93
S.E ± for varieties (B) 1.32
S.E ± for AxB (interaction) 1.86

V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
4.1.2. Percentage of high infection:-

Application of water and fertilizer did not affect the percentage of high infection in both seasons (appendices 4 and 5), whereas the varieties and the interaction between irrigation and fertilizer and varieties significantly (p<0.01) affected the incidence (p<0.01) in both seasons (appendices 4 and 5).

In both seasons, V₄ had a significantly higher percentage of high infection compared to all other varieties, except V₂ in the first season, when there was no significant difference between the two varieties (table 2). Moreover V₂ recorded a significantly higher percentage of high infection compared to V₁ and V₂ in the first season, and only V₁ in the second season (table 2). Similarly V₃ had a significantly higher percentage of high infection than V₁ only in the second season (table 2).

The interaction between long watering interval and fertilization and V₂ in the first season and long watering interval and fertilization and V₄ in the second season recorded a significantly higher percentage of high infection in comparison to all other interactions (table 2), whereas long watering interval and fertilization X V₁ interaction and V₃ interaction in the first season and long watering interval and fertilization in the second season resulted in a significantly lower percentage of the character at all occasions (table 2).

4.1.3. Percentage of medium infection:-

The percentage of medium infection was significantly affected (p<0.01) by application of water and fertilizer, varieties and their interaction, in both season (appendices 4 and 5).
Table (2): Effect of irrigation and fertilization level on high tuber infection incidence.

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<td></td>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
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<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(34.7)</td>
<td>30.3</td>
<td>(32.6)</td>
<td>29.6</td>
<td>(41.5)</td>
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<td></td>
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<td></td>
<td>de</td>
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<td>b</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(33.0)</td>
<td>30.8</td>
<td>(45.5)</td>
<td>50.8</td>
<td>(29.7)</td>
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<td></td>
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<td></td>
<td>de</td>
<td>a</td>
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</tr>
<tr>
<td>Var.mean</td>
<td></td>
<td>(33.9)</td>
<td>(39.1)</td>
<td>40.2</td>
<td>(35.6)</td>
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<tr>
<td></td>
<td></td>
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<td>a</td>
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S.E ± for irrig. And fert. (A) 0.62
1.55
S.E ± for varieties (B) 0.87
2.19
S.E ± for A×B (interaction) 1.24
3.10
V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
In the first season, long watering interval and fertilization recorded a significantly higher percentage of medium infection than that of short watering interval and fertilization (table 3), whereas the reverse was true in the second season. In both seasons, V₂ had a significantly higher percentage of medium infection as compared to all other varieties, except V₁ in the first season (table 3). On the other hand, V₄ gave a significantly lower percentage of medium infection as compared to all other varieties only in the first season (table 3).

The interaction between long watering interval and fertilization and V₂ in the first season recorded a significantly higher percentage of medium infection (table 3), however, in the second season, the interaction between short watering interval and fertilization and V₂ had a significantly higher percentage of medium infection (table 3). Meanwhile, the interaction between short watering interval and fertilization and V₄ and between long watering interval and fertilization and V₁ recorded a significantly lower percentage of medium infection in the first and second season, respectively (table 3).

4.1.4. Percentage of low infection:

Application of water and fertilizer significantly influenced percentage of low infection (p<0.01) only in the second season, whereas the varieties and the interaction between application of water and fertilizer and varieties significantly affected this parameter in both seasons (appendices 4 and 5).

In the second season, the short watering interval and fertilization recorded a significantly higher percentage of low infection than that of long watering interval and fertilization (table 4). The average percentage of low
infection was recorded in the second season as compared to the first season for both short and long watering intervals and fertilization treatments.
**Table (3):** Effect of irrigation and fertilization level on medium tuber infection incidence.

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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(38.1) b</td>
<td>(36.5) bc</td>
<td>(36.5) bc</td>
<td>(30.9) d</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(36.0) bc</td>
<td>(42.1) a</td>
<td>(36.9) bc</td>
<td>(33.8) cd</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(37.1) ab</td>
<td>(39.3) a</td>
<td>(36.7) b</td>
<td>(32.4) c</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.6
1.2
S.E ± for varieties (B) 0.8
1.7
S.E ± for A×B (interaction) 1.2
2.4
V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
  Percent transformed to Aresin between parentheses.
Table (4): Effect of irrigation and fertilization level on low tuber infection incidence.

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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrgation &amp; fertilization</td>
<td>(39.0) 39.6 ab</td>
<td>(34.3) 32.6 cd</td>
<td>(32.1) 28.5 d</td>
<td>(33.6) 31.9 d</td>
</tr>
<tr>
<td></td>
<td>(34.8) 33.2 a</td>
<td>(11.3) 12.5 a</td>
<td>(6.0) 4.2 b</td>
<td>(0.0) 0.0 c</td>
</tr>
<tr>
<td></td>
<td>(34.8) 33.2 a</td>
<td>(11.3) 12.5 a</td>
<td>(6.0) 4.2 b</td>
<td>(0.0) 0.0 c</td>
</tr>
<tr>
<td></td>
<td>(34.8) 33.2 a</td>
<td>(11.3) 12.5 a</td>
<td>(6.0) 4.2 b</td>
<td>(0.0) 0.0 c</td>
</tr>
<tr>
<td>Low irrgation &amp; fertilization</td>
<td>(39.8) 40.5 ab</td>
<td>(19.5) 20.0 e</td>
<td>(38.6) 38.9 bc</td>
<td>(43.3) 47.0 a</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(39.4) 40.1 a</td>
<td>(26.9) 26.3 c</td>
<td>(35.4) 33.7 b</td>
<td>(38.5) 39.5 ab</td>
</tr>
<tr>
<td></td>
<td>(5.7) 6.3 bc</td>
<td>(8.7) 8.4 a</td>
<td>(0.0) 0.0 d</td>
<td>(3.7) 3.0 bc</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.8
S.E ± for varieties (B) 1.1
S.E ± for A×B (interaction) 1.6

V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
The reduction under the short and long watering intervals and fertilization treatments between the second and first season were 82.8 % and 91.5 %, respectively (table 4).

In the first season, $V_1$ recorded a significantly higher percentage of low infection as compared to $V_2$ and $V_3$ but not $V_4$ (table 4). Similarly, $V_3$ and $V_4$ which were not significantly different from each, recorded a significantly different from each, recorded a significantly higher percentage of low infection than $V_2$ (table 4). In the second season, $V_2$ had a significantly higher percentage of low infection compared to all other varieties (table 4). This was followed by $V_1$, $V_4$ and $V_3$, respectively (table 4).

Long watering interval and fertilization $XV_4$ and short watering interval and fertilization $XV_1$ interactions resulted in a significantly higher percentage of low infection in the first and second seasons, respectively, whereas the lower percentage of low infection was recorded under long watering interval and fertilization $XV_2$ in the first season and between short and long watering intervals and fertilization and most varieties in the second season (table 4).

4.1.5. **Percentage of high infection among large size tubers:-**

Appendix 4 showed that the percentage of high infection among the large size tubers was significantly ($p<0.01$) affected by application of irrigation water and fertilizer, varieties and their interaction in both seasons.

Short watering interval and fertilization in both seasons resulted in a significantly higher percentage of high infection among large size as compared to long watering interval and fertilization (table 5). The reduction of percentage of high infection at large size between the second and first
season was 23.7% and 88.3% for short watering interval and fertilization and long watering interval and fertilization, respectively.

As for varieties, V3 in the first season and V4 in the second season recorded a significantly higher percentage of high infection among the large size tubers. This was followed by V2 in the first season, V2 and V3 in the second season and finally V1 in both seasons (table 5). The reduction of percentage of high infections among large size tubers among varieties between the second seasons as compared to the first season were 100%, 65.6%, 69.5% for V1, V2 and V3, respectively.

The interactions long watering interval and fertilization XV2 and short watering interval and fertilization XV4 recorded a significantly higher percentage of high infection among large size tubers in the first and second seasons, respectively, whereas long watering interval and fertilization XV1 and XV1 and V2 in the both seasons and short watering interval and fertilization XV1 in the second season gave a significantly lower percentage of high infection among large size tubers (table 5).

4.1.6. **Percentage of medium infection among large size tubers:**

In both seasons, percentage of medium infection among large size tubers was significantly ($p<0.01$) affected by application of water and fertilizer, varieties and degree of their infection (appendices 4 and 5).

In both seasons, short watering interval and fertilization treatment had a significantly high percentage of medium infection among large size tubers than irrigation and fertilization treatment (table 6). The reduction in percentage of medium infection among large size tubers between short and long watering intervals and fertilization treatments in second season as compared to the first season was 35.1% and 78.1%, respectively.
Table (5): Effect of irrigation and fertilization level on percent of high infection among large size tubers.

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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(31.6)</td>
<td>(17.9)</td>
<td>(41.9)</td>
<td>(34.1)</td>
</tr>
<tr>
<td></td>
<td>33.8</td>
<td>17.1</td>
<td>44.7</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>d</td>
<td>b</td>
<td>e</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(5.6)</td>
<td>(51.6)</td>
<td>(34.9)</td>
<td>(14.0)</td>
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<td></td>
<td>5.6</td>
<td>61.2</td>
<td>33.8</td>
<td>11.0</td>
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<tr>
<td></td>
<td>e</td>
<td>a</td>
<td>c</td>
<td>d</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(18.6)</td>
<td>(34.8)</td>
<td>(38.4)</td>
<td>(24.1)</td>
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<td></td>
<td>19.7</td>
<td>39.2</td>
<td>39.3</td>
<td>21.2</td>
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<tr>
<td>S.E ± for irrig. And fert. (A)</td>
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<td></td>
<td>1.3</td>
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<tr>
<td>S.E ± for varieties (B)</td>
<td></td>
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<tr>
<td></td>
<td>1.9</td>
<td></td>
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<tr>
<td>S.E ± for A×B (interaction)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>2.7</td>
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<tr>
<td>V₁ = Alpha</td>
<td></td>
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<tr>
<td>V₂ = Drag a</td>
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<td></td>
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<tr>
<td>V₃ = Diamond</td>
<td></td>
<td></td>
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<tr>
<td>V₄ = Alpha control</td>
<td></td>
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</tbody>
</table>

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
Table (6): Effect of irrigation and fertilization level on percent of medium infection among large size tubers.

<table>
<thead>
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</thead>
<tbody>
<tr>
<td></td>
<td>V1</td>
<td>V2</td>
<td>V3</td>
<td>V4</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(45.0) a</td>
<td>(20.1) e</td>
<td>(43.5) ab</td>
<td>(37.5) bc</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(32.8) cd</td>
<td>(27.2) de</td>
<td>(43.3) ab</td>
<td>(9.7) f</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(38.9) a</td>
<td>(23.7) b</td>
<td>(43.4) a</td>
<td>(23.6) b</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 1.3
S.E ± for varieties (B) 1.8
S.E ± for A×B (interaction) 2.5

V1 = Alpha
V2 = Drag a
V3 = Diamond
V4 = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
In the first season $V_1$ and $V_3$ recorded a significantly higher percentage of medium infection among large size tubers as compared to $V_2$ and $V_4$ which were showed no significant difference between them (table 6).

In the second season, $V_2$ recorded a significantly higher percentage of medium infection among large size tubers compared to all other varieties (table 6). This was followed by $V_4$, $V_1$ and $V_3$, respectively (table 6). The percentage of medium infection among large size tubers was reduced under $V_1$ and $V_3$ by 67.9% and 86.7%, respectively in the second season as compared to the first season.

The interaction, short watering interval and fertilization $XV_1$ in the first season and $XV_2$ in the second season recorded significantly higher percentage of medium infection among large size tubers, whereas the interaction short watering interval and fertilization $XV_2$ in the first season and long watering interval and fertilization $XV_1$, $XV_2$ and $XV_3$ interactions recorded a significantly lower percentage of medium infection among the large size tubers in comparison to all other interactions (table 6). The percentage of medium infection among large size tubers were more reduced in the second season in comparison to the first season, specially under the long watering interval and fertilization treatment (table 6).

4.1.7. Percentage of low infection among large size tubers:-

Application of water and fertilizer, varieties and their interaction significantly ($p<0.01$) affected the percentage of low infection among large size tuber in both seasons (appendices 4 and 5).

In both seasons, short watering interval and fertilization treatment resulted in a significantly higher percentage of low infection among large size tubers as compared to long watering interval and fertilization treatment.
the percentage of infection among medium size tubers was reduced under short and long watering intervals and fertilization by about 67.0% and 79.3%, respectively for the second season as compared to the first one (table7).

On the other hand, $V_1$, $V_3$ and $V_4$ which showed no significant differences between them in the first season had a significantly higher percentage of low infection among large size tubers than $V_2$ (table7). However $V_2$ in the second season showed a significantly higher percentage of high infection among medium size tubers as compared to all other varieties (table7). This was followed by $V_4$, $V_1$ and $V_3$, respectively (table7).

In the first season, the interaction; long watering interval and fertilization $XV_1$ recorded a significantly higher percentage of low infection among large size tubers, whereas the interaction long watering interval and fertilization $XV_2$ showed a significantly lower percentage of low infection among large size tubers for the same time (table7).

In the second season, the infections, short watering interval and fertilization $XV_4$ and long watering interval and fertilization $XV_2$ recorded a significantly higher percentage of low infection among medium size tubers, whereas short watering interval and fertilization $XV_3$, long watering interval and fertilization $XV_1$, $V_3$ and $V_4$ interaction showed a significantly lower percentage of this character (table7). Most of the interactions between the water and fertilization and varieties in the second season showed an extreme reduction in percentage of lower infection among large size tubers in comparison to the first season (table7).
**Table(7):** Effect of irrigation and fertilization level on percent of low infection among large size tubers.

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<tbody>
<tr>
<td></td>
<td>V&lt;sub&gt;1&lt;/sub&gt;</td>
<td>V&lt;sub&gt;2&lt;/sub&gt;</td>
<td>V&lt;sub&gt;3&lt;/sub&gt;</td>
<td>V&lt;sub&gt;4&lt;/sub&gt;</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(39.9)</td>
<td>(26.1)</td>
<td>(38.5)</td>
<td>(41.8)</td>
</tr>
<tr>
<td></td>
<td>41.3 a</td>
<td>20.0 b</td>
<td>38.5 a</td>
<td>44.7 a</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(42.1)</td>
<td>(7.3)</td>
<td>(35.0)</td>
<td>(37.8)</td>
</tr>
<tr>
<td></td>
<td>45.1 a</td>
<td>5.9 c</td>
<td>33.2 a</td>
<td>37.5 a</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(41.0)</td>
<td>(16.7)</td>
<td>(36.7)</td>
<td>(39.8)</td>
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<tr>
<td></td>
<td>43.2 a</td>
<td>13.0 b</td>
<td>35.9 a</td>
<td>41.1 a</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) = 1.4
S.E ± for varieties (B) = 2.0
S.E ± for A×B (interaction) = 2.9

V<sub>1</sub> = Alpha
V<sub>2</sub> = Drag a
V<sub>3</sub> = Diamond
V<sub>4</sub> = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
4.1.8. **Percentage of high infection among medium size tubers:**

Application of water and fertilizer as well as the varieties significantly (p<0.01) affected percentage of high infection among medium size tubers only during the second season, whereas the interaction affected this character in both seasons, (appendices 4 and 5).

In the second season, short watering interval and fertilization treatment had a significantly higher percentage of high infection among medium size than long watering interval and fertilization treatment (table 8). The percentage of high infection among medium size tubers in the second season was significantly higher under V₄, followed by V₂, V₃ and finally V₁ (table 8).

The interaction, long watering interval and fertilization XV₁ in the first season recorded a significantly higher percentage of high infection among medium size tubers at all occasions, but in the second season, the reverse was true (table 8). Also short watering interval and fertilization XV₄ interaction in the second season gave a significantly higher percentage of high infection among medium size tubers, while the interaction, short watering interval and fertilization XV₁ in the first season reported significantly lower percentage of this character at all occasions (table 8).

4.1.9. **Percentage of medium infection among medium size tubers:**

Application of water and fertilizer significantly affected percentage of medium infection among medium size tubers only in the first season (appendices 4 and 5), whereas varieties and the interaction between irrigation and fertilization and varieties significantly (p<0.01) affected this character in both seasons (appendices 4 and 5).
**Table (8):** Effect of irrigation and fertilization level on percent of high infection among medium size tubers.

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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrg. &amp; fertilization</td>
<td>(16.5)</td>
<td>15.0 d</td>
<td>(46.5) abc</td>
<td>(38.9) bc</td>
</tr>
<tr>
<td>Low irrg. &amp; fertilization</td>
<td>(54.2) a</td>
<td>58.3 c</td>
<td>(33.5) abc</td>
<td>(37.5) bc</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(35.4) a</td>
<td>36.7 a</td>
<td>(40.0) a</td>
<td>(38.2) a</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 2.3
1.0
S.E ± for varieties (B) 3.3
1.4
S.E ± for A×B (interaction) 4.6
2.0
V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
In the first season short watering interval and fertilization treatment exceeded long watering interval and fertilization treatment in percentage of medium infection among medium size tubers (table 9). The reduction in percentage of medium infection among medium size tubers under short and long watering intervals and fertilization at the second season in relation to the first season were 37.8% and 19.1%, respectively (table 9).

In the second season, V₁ recorded a significantly higher percentage of medium infection among medium size tubers as compared to all other varieties, however, the reverse was true in the first season (table 9). The reduction in percentage of medium infection among medium size tubers during the second season for V₂, V₃ and V₄ were, 43.2%, 36.7% and 44.0%, respectively (table 9).

In the first season, long watering interval and fertilization XV₄ interaction had a significantly higher percentage of medium infection among medium size tubers, while short watering interval and fertilization XV₄ in the second season gave a significantly higher percentage of this character (table 9). On the other hand, the interaction long watering interval and fertilization XV₁ in the first season and XV₄ in the second season resulted in a significantly lower percentage of medium infection among medium size tubers (table 9).
Table (9): Effect of irrigation and fertilization level on percent of medium infection among medium size tubers.

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<tbody>
<tr>
<td></td>
<td>V1</td>
<td>V2</td>
<td>V3</td>
<td>V4</td>
</tr>
<tr>
<td>Heavy irrgation &amp; fertilization</td>
<td>(30.0)</td>
<td>(33.5)</td>
<td>(34.3)</td>
<td>(33.8)</td>
</tr>
<tr>
<td>Light irrigation &amp; fertilization</td>
<td>(17.0)</td>
<td>(33.2)</td>
<td>(30.5)</td>
<td>(37.0)</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(23.5)</td>
<td>(33.4)</td>
<td>(32.4)</td>
<td>(32.4)</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.7 1.1
S.E ± for varieties (B) 1.0 1.6
S.E ± for A×B (interaction) 1.4 2.3

V1 = Alpha
V2 = Drag a
V3 = Diamond
V4 = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
4.1.10. Percentage of low infection among medium size tubers:

In both seasons, application of water and fertilizer, varieties and their interaction significantly \((p<0.01)\) affected the percentage of low infection among medium size tubers (appendices 4 and 5).

The percentage of low infection among medium size tubers was significantly greater under short watering interval and fertilization treatment as compared to the long watering interval and fertilization in both seasons (table 10). The reduction in percentage of medium infection among medium size tubers between the second season and the first season was 71.3\% for short watering interval and fertilization and 100\% for long watering interval and fertilization (table 10).

In the first season, \(V_4\) recorded a significantly higher percentage of low infection among medium size tubers as compared to all other varieties, but in the second season the reverse was true (table 10). On the other hand, there were no significant difference for the percentage of low infection among medium size tubers among \(V_2\), \(V_3\) and \(V_4\) for the percentage of low infection among medium size tubers in both seasons (table 10). The reduction in percentage of lower infections among medium size tubers during the second season were 43.2\%, 36.7\% and 44.0\% for \(V_2\), \(V_3\) and \(V_4\) respectively (table 10).

The interaction, short watering interval and fertilization \(XV_3\) in the first season and \(XV_4\) in the second season resulted in a significantly higher percentage of low infection among medium size tubers (table 10), whereas, the interaction, long watering interval and fertilization \(XV_1\) in the first season and \(XV_4\) in the second season had a significantly lower percentage of low infection among medium size tubers (table 10).
Table (10): Effect of irrigation and fertilization level on percent of low infection among medium size tubers.

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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrg. &amp; fertilization</td>
<td>(36.7) c 36.4 b</td>
<td>(40.6) b 34.4 c</td>
<td>(35.9) b 44.0 b 41.5 b</td>
<td></td>
</tr>
<tr>
<td>Low irrg. &amp; fertilization</td>
<td>(34.0) e 31.4 c 30.3 d</td>
<td>(26.1) c 27.7 d 31.6 c</td>
<td>(45.8) a 51.3 a 45.8 b</td>
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<tr>
<td>Var.mean</td>
<td>(35.4) b 33.9 b</td>
<td>(33.4) b 36.4 b</td>
<td>(33.8) b 31.1 b 47.7 a</td>
<td></td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.6 0.3 0.6 0.3 0.6 0.3 0.6 0.3 0.6 0.3
S.E ± for varieties (B) 0.9 0.4 0.9 0.4 0.9 0.4 0.9 0.4 0.9 0.4
S.E ± for A×B (interaction) 1.2 0.5 1.2 0.5 1.2 0.5 1.2 0.5 1.2 0.5

V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
4.1.11. **Percentage of high infection among small size:**

Percentage of high infection among small size tubers was significantly (p<0.01) affected by application of water and fertilizer, varieties and their interaction in both seasons (appendices 4 and 5).

In the first season, short watering interval and fertilization treatment resulted in a significantly higher percentage of high infection among small size tubers (table 11), whereas the reverse was true in the second season (table 11). V₁ in the first season and V₄ in the second season recorded a significantly higher percentage of high infection among small size tubers as compared to all other varieties (table 11). On the other hand, V₃ and V₄ in the first season recorded a significantly higher percentage of high infection among small size tubers than V₂, whereas V₂ in the second showed a significantly higher percentage of this character than V₁ (table11).

The interactions short watering interval and fertilizationnXV₁ in the first season and long watering interval and fertilization XV₂ in the second season obtained a significantly higher percentage of high infection among small size tubers (table 11), whereas the interactions long watering interval and fertilization XV₂ in the first season and short watering interval and fertilization XV₂ in the second season recorded a significantly lower percentage of high infection at small size tubers (table 11).

4.1.12. **Percentage of medium infection among small size tubers:**

In both seasons, the percentage of medium infection among small size tubers was significantly influenced by application of water and fertilizer, varieties and their interaction (appendices 4 and 5).

In the first season, long watering interval and fertilization treatment recorded a significantly high percentage of medium infection among small
Table (11): Effect of irrigation and fertilization level on percent of high infection among small size tubers.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>$V_1$</td>
<td>$V_2$</td>
<td>$V_3$</td>
<td>$V_4$</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(44.2) a</td>
<td>(29.4) cd</td>
<td>(26.9) cd</td>
<td>(35.6) b</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(24.6) d</td>
<td>(12.8) e</td>
<td>(30.4) bc</td>
<td>(25.4) cd</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(34.4) a</td>
<td>(21.1) c</td>
<td>(28.7) b</td>
<td>(30.5) b</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.9
S.E ± for varieties (B) 1.3
S.E ± for A×B (interaction) 1.8

$V_1$ = Alpha
$V_2$ = Drag a
$V_3$ = Diamond
$V_4$ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
size, tubers whereas the reverse was true in the second season (table 12). The reductions in percentage of medium infection among small size tubers between the second season and the first season were 75.0% and 84.2% for short and long watering intervals and fertilization treatments respectively (table 12).

$V_1$ and $V_4$ in the first season resulted in a significantly higher percentage of medium infection among small size tubers than $V_2$ and $V_3$ in which the former variety ($V_2$) had also a significantly higher percentage of the character than the later one ($V_3$) (table 12).

The reduction in percentage of medium infection among small size tubers during the second season among $V_1$, $V_2$, $V_3$ and $V_4$ were 83.1%, 77.2%, 85.0% and 76.5% respectively (table 12).

The significantly high percentage of medium infection among small size tubers was obtained by the interactions long watering interval and fertilization $XV_4$ in the first season and short watering interval and fertilization $XV_2$ in the second season (table 12). On the other hand, the interaction, short watering interval and fertilization $XV_2$ and $XV_3$ in the first season and long watering interval and fertilization $XV_2$ in the second season resulted in a significantly lower percentage of medium infection among small size tubers (table 12). Most of the interactions between water and fertilizer and varieties showed an extreme reduction in percentage of medium infection among small size tubers in comparison to the first season (table 12).
Table (12): Effect of irrigation and fertilization level on percent of medium infection among small size tubers.

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<tr>
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<tbody>
<tr>
<td></td>
<td>V₁</td>
<td>V₂</td>
<td>V₃</td>
<td>V₄</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(40.0)</td>
<td>(27.8)</td>
<td>(29.2)</td>
<td>(31.6)</td>
</tr>
<tr>
<td></td>
<td>41.9</td>
<td>22.0</td>
<td>21.9</td>
<td>30.9</td>
</tr>
<tr>
<td></td>
<td>ab</td>
<td>c</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(38.8)</td>
<td>(41.4)</td>
<td>(31.5)</td>
<td>(43.5)</td>
</tr>
<tr>
<td></td>
<td>39.8</td>
<td>43.8</td>
<td>27.5</td>
<td>43.0</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>ab</td>
<td>c</td>
<td>a</td>
</tr>
<tr>
<td>Var.mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(39.4)</td>
<td>(34.6)</td>
<td>(30.4)</td>
<td>(37.6)</td>
</tr>
<tr>
<td></td>
<td>40.9</td>
<td>32.9</td>
<td>24.7</td>
<td>37.0</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.7
0.6
S.E ± for varieties (B) 1.0
0.8
S.E ± for A×B (interaction) 1.4
1.1
V₁ = Alpha
V₂ = Drag a
V₃ = Diamond
V₄ = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.
4.1.13. Percentage of low infection among small size tubers:

In both seasons, percentage of low infection among small size tubers was significantly affected by irrigation and fertilization, varieties and their interaction (appendices 4 and 5).

The percentage of low infection among small size tubers was significantly greater under short watering interval and fertilization treatment as compared to long watering interval and fertilization in both seasons (Table 13). The reduction in percentage of low infection among small size tubers between the second and first season was 75.3% and 100% for short and long watering intervals and fertilization treatment, respectively (Table 13).

In both seasons, V3 obtained a significantly higher percentage of low infection among small size tubers as compared to all other varieties, except V4 at the first season (Table 13). This was followed by V4, V3, V1, V2 and V4 in the second season (Table 13). The reductions percentage of low infection among small size tubers for V1, V2, V3 and V4 were 85.8%, 100%, 59.0% and 100%, respectively (Table 13).

The interactions, short watering interval and fertilization on XV4 in the first season and short watering interval and fertilization XV3 in the second season resulted in a significantly higher percentage of low infection among small size tubers (Table 13), whereas the interactions, long watering interval and fertilization XV2 in the first season and XV1, V2, V3 and V4 in the second season in addition to short watering interval and fertilization XV2 and XV4 in the second season recorded a significantly lower percentage of low infection among small size tubers (Table 13). The percentage of low infection among small size tubers was extremely reduced among the
different interaction between water and fertilizer and varieties in the second season as compared to the first season (table 13).

4.1.14. Total yield (Ton / Fed):

   In both seasons, application of water and fertilizer, varieties and their interaction significantly (p<0.05) affected total yield (appendices 4 and 5).

   In both seasons, long watering interval and fertilization treatment gave significantly higher total yield as compared to short watering interval and fertilization (table 14). Total yield increased during the second season as compared to the first season and the percentage of increment was 48.3 % and 20.9% for the short and long watering intervals and fertilization treatment (table 14).

   Total yield of V₃ was significantly high as compared to other varieties in both seasons, except V₂ in the first season (table 14). On the other hand, V₂ had a significantly higher total yield in comparison to both V₁ and V₄ in both seasons and V₁ recorded a significantly greater yield over V₄ only in the second season (table 14).

   All varieties in the second season out – yielded the first season and the percentage increment was 24.0%, 21.45, 34.5% and 22.6% for V₁, V₂, V₃ and V₄, respectively (table 14).

   The interaction long watering interval and fertilization XV₃ gave a significantly higher yield at all occasions, whereas the interaction, short watering interval and fertilization XV₄ recorded a significantly lower yield as compared to all other interactions in both seasons (table 14).
Table(13): Effect of irrigation and fertilization level on percent of low infection among small size tubers.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>V1</td>
<td>V2</td>
<td>V3</td>
<td>V4</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>(25.6)</td>
<td>(35.3)</td>
<td>(31.6)</td>
<td>(37.7)</td>
</tr>
<tr>
<td></td>
<td>20.0</td>
<td>33.4</td>
<td>28.9</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>ab</td>
<td>bc</td>
<td>a</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>(22.0)</td>
<td>(15.8)</td>
<td>(34.4)</td>
<td>(26.0)</td>
</tr>
<tr>
<td></td>
<td>15.1</td>
<td>13.8</td>
<td>32.0</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>e</td>
<td>ab</td>
<td>cd</td>
</tr>
<tr>
<td>Var.mean</td>
<td>(23.8)</td>
<td>(25.6)</td>
<td>(33.0)</td>
<td>(31.9)</td>
</tr>
<tr>
<td></td>
<td>17.6</td>
<td>23.6</td>
<td>30.5</td>
<td>29.1</td>
</tr>
<tr>
<td></td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 1.0
S.E ± for varieties (B) 1.4
S.E ± for A×B (interaction) 2.0

V1 = Alpha
V2 = Drag a
V3 = Diamond
V4 = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
- Percent transformed to Aresin between parentheses.

69
**Table (14):** Effect of irrigation and fertilization on total yield (ton/fed).

<table>
<thead>
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</thead>
<tbody>
<tr>
<td></td>
<td>V1</td>
<td>V2</td>
<td>V3</td>
<td>V4</td>
</tr>
<tr>
<td>Heavy irrigation &amp; fertilization</td>
<td>1.53 cd</td>
<td>1.67 cd</td>
<td>1.67 cd</td>
<td>0.85 e</td>
</tr>
<tr>
<td>Low irrigation &amp; fertilization</td>
<td>1.45 d</td>
<td>2.00 ab</td>
<td>2.05 a</td>
<td>1.78 bc</td>
</tr>
<tr>
<td>Var.mean</td>
<td>1.49 b</td>
<td>1.84 a</td>
<td>1.86 a</td>
<td>1.32 b</td>
</tr>
</tbody>
</table>

S.E ± for irrig. And fert. (A) 0.04
S.E ± for varieties (B) 0.08
S.E ± for A×B (interaction) 0.11

V1 = Alpha
V2 = Drag a
V3 = Diamond
V4 = Alpha control

- Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
4.2 Laboratory experiment:

Statistical analysis showed that the number of colonies of *S. scabies* was significantly lower under both 5 and 10 ml concentration of neem extraction as compared to 2.5 ml concentration (table 15). Also the table shows that the number of colonies of the bacterium was significantly increased by increasing the duration of application of neem extraction.

Meanwhile, the highest number of colonies for the pathogen was recorded under the interaction 3rd wk of application X 2.5 ml concentration, whereas the lowest infection was recorded under the interaction 1st wk of application X 10 ml concentration, (table 15).

4.3 Surveying study:

Surveying study indicated that 98.0% of potato producers involved in the study mentioned that the output loss due to infection is great, although most cultural practices mentioned in the questionnaires were looked to be suitable (appendix 6). The result of questionnaire, (appendix 6) showed that most producers used healthy seeds (99%), stored and introduced seed (99%), pieces seeds (100%), high dose of fertilizer (98%) and different types of soil (98%). Moreover, most of interviewed farmers have either island or near from the Nile banks (75%) applied fertilizer more than one time (98%), planted their crop in early November (99%), used pumps for irrigation (100%), irrigated every 10 days as an interval (99%), weeding more than one time (100%).

Table (16) shows that there were positive and significant correlation between economic losses due to infection all of healthness of cultivated seeds, seed source, fertilizer dose, fertilizer application, distance of land from the Nile and the fate of infected tuber, whereas there was a
positive and significant correlation between economic losses and irrigation interval. On the other hand, there was no significant correlation between economic losses and sowing date, tool sterility for cutting tuber and land flooding (table 16).
Table (15): Effect of Neem correlation, duration of application period and their interaction on number of colonies of *Streptomyces scabies*.

<table>
<thead>
<tr>
<th>Dose level</th>
<th>2.5 %</th>
<th>5.0 %</th>
<th>10.0 %</th>
<th>Time Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; wk</td>
<td>8.53 f</td>
<td>6.67 g</td>
<td>5.80 g</td>
<td>7.00 c</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; wk</td>
<td>12.87 ca</td>
<td>12.00 de</td>
<td>11.20 e</td>
<td>12.02 b</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; wk</td>
<td>17.53 a</td>
<td>13.93 bc</td>
<td>14.27 b</td>
<td>15.24 a</td>
</tr>
<tr>
<td>Dose mean</td>
<td>12.78 a</td>
<td>10.87 b</td>
<td>10.42 b</td>
<td></td>
</tr>
</tbody>
</table>

S.E ± For time
S.E ± For dose
S.E ± for time x dose (interaction)
* Means followed by similar letters are not significantly different at 0.05 level of probability according to DNMRT.
Table (16): Correlation coefficient (r) values showed the degree of association between economic losses and some cultural practices that affect potato infection.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Status of cultivated seeds</th>
<th>Seed Source</th>
<th>Sowing date</th>
<th>Sterilization of tuber cutter</th>
<th>Method of tuber cultivation</th>
<th>Irrigation interval</th>
<th>Method of irrigation</th>
<th>Number of weedicings</th>
<th>Fertilizer dose (urea)</th>
<th>Number of fertilizer applications</th>
<th>Distance of land from Nile</th>
<th>Land flooding</th>
<th>Infected tuber</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Losses</td>
<td>0.308**</td>
<td>0.308**</td>
<td>-0.013 N.S.</td>
<td>-0.014 N.S.</td>
<td>-0.308**</td>
<td>-</td>
<td>0.097</td>
<td>0.209*</td>
<td>0.264**</td>
<td>0.451**</td>
<td>0.118 N.S</td>
<td>0.472**</td>
<td>0.955**</td>
<td></td>
</tr>
</tbody>
</table>

N.s, *, **: not significant and significant correlation at 0.05 and 0.01 level of probability respectively
Fig.1: Shows Alpha seed tubers.
Fig.2: Shows Draga seed tubers.
Fig.3: Shows Diamond seed tubers.
Fig. 4: Shows Three varieties of healthy potato tubers (seeds) Diamond, Draga and Alpha
Fig.5: Shows Three varieties of healthy potato crop – Alpha, Draga and Diamond.
Fig. 6: Shows three varieties of infected potato tubers (common scab) Alpha, Draga and Diamond (from left to right).
Figure (7): A match between a healthy and infected tubers of three varieties Alpha, Draga and Diamond. (from left to right)

A: Healthy
B: Infected
Fig. 8: Shows the colonies of *Streptomyces scabies* in laboratory on P.D.A media.
Fig.9: General landscape of the experimental field.
Fig. 10: Prof. Baghdadi (supervisor) inspecting the experimental field at Shihanab region.
Fig.11: Potato traditional harvesting in the experimental field.
Fig.12: The collection of potato crop in the experimental field.
Fig.13: Weighting and grading of potato crop in the experimental field.
CHAPTER FIVE
DISCUSSION AND CONCLUSION

5.1 Discussion

The importance of potato has begun to increase since the industrial revolution in mid of the nineteenth century so the production of potato increased as a result of the increase in the populations mainly in the cities. Potato contains a high percentage of energy and makes a reasonable source of income for poor families and this makes it the prefered food for a great number of the worlds population.

Potato suffers from many bacterial, fungal, virual and physiological diseases all over the world. In The Sudan potato infected with common scab which is caused by \textit{S. scabies}. In spite of improvement in the consumer taste and sense, the increase in the productivity and the cultivated areas of potato, the disease (potato scab) comes to be one of the factors of tubers price decrease. And as a result of this the income of the farmer decreases and this leads negatively to decrease in the domestic and the national income for this, the disease should be controlled with best and minimum cost.

Currently there is a growing awaken to avoid excessive use of pesticides in food crops, mainly vegetables. The chemical pesticides are poisonous and cause environmental contamination which lead to environment deterioration and expose mankind’s health to danger, for this, International Pest Management has been initiated, which aims to reduce the usage of pesticides and to concentrate on improving and developing husbandry practices and other methods useful in resisting and decreasing the danger of such diseases.
Through the international and national experiments, and according to the result of the research conducted at Shihanab area (North of Khartoum) to test the influence of some husbandry practices and Neem extract in controlling common scab of potato, we come to say that core of the study is to reduce the usage of chemical control in resisting plant diseases, which abstract:

In the present study application of short watering interval and fertilization in both seasons had significantly higher percentage of general infection, this is in contrast to studies of Davis et al., (1974); Davis (1976); Adams et al., (1987); and Lordia et al., (1997), whereas Abu salih and Baghdadi (1961); Khalifa (1965, 1966) reported that nitrogen applied to the soil as urea has resulted in an increase in incidence of fusarium wilt of cotton (*Fusarium oxysporum. f vasinfectun*), while Tharp and Wadleigh (1940) mentioned that an increase in wilt incidence with the application of nitrates and ammonia. Sulachana (1952); Kalyanasundaram, (1954) mentioned that soil amendments with manganese increased wilt incidence. Naim et al (1966) reported that dry soil increased infection of fusarium wilt of cotton, also Tupenevich and Menlikiev, (1966) mentioned that sowing of lucern, rice and maize as preceding crops to cotton reduce infection of fusarium wilt.

In the first season V₃ (Diamond) recorded a significantly higher percentage of general infection rate as compared to all other varieties. Whereas V₁ (Alpha ) had a significantly lower percentage of general infection rate as compared to all other varieties, this maybe due to adaptatim of Alpha to local conditions, oldest imported and favoured variety to potato producers for its good characters. Similar result was reported by Ali, (2000).
Short watering interval and fertilization in both seasons resulted in a significantly higher percentage of high infection among large size tubers as compared to long watering interval and fertilization, this is in contrast to Lapwood, (1968) and Hering (1970) results. It maybe due to soil moisture. Leed et al (1999) reported that water applications of around 12 mm are now common at tuber initiation in potato to control scab disease and application depths of around 20-25 mm are common for the remainder of the irrigation season.

The percentage of low infection among small size was significantly greater under short watering interval and fertilization treatment as compared to long watering interval and fertilization in both seasons. Similar results were reported by Sanford, (1923). Ahmed (1999) mentioned that, full irrigation at the primary stage of tuber germination control scab of potato and also avoid drought (dryness). While Agrios, (1985) reported that numerous soil fungi like, phytophthora, Rhizoctonia, Sclerotinia and a few bacteria such as Erwinia, pseudomonas and some Nematoda usually effect sever symptoms on plants, while soil moisture and not flooded. Whereas a few such as S. scabies (common scab of potato) more severity at dryness relatively. Common scab of potato can be reduce grater by increasing soil moisture during tuber initiation and many weeks after that.

In both seasons, long watering interval and fertilization treatment gave significantly higher total yield as compared to short watering interval and fertilization. Total yield was significantly increased under V3 (Diamond) as compared to other varieties in both seasons except V2 (Draga) in the first season. Similar result was reported by Vanloon, (1989), also Ahmed, (1999) mentioned that pH 4.8 – 5.4 is unsuitable condition for S. scabies (common
scab of potato), and for this farmers preferred it, but this is not means that it is the best condition for potato germination. In the other hand it in contrast to Neetasoon (1989) study.

The investigation and laboratory inspection for infected tuber from the experiment field showed occurrence of *S. scabies* (common scab of potato) which is known by tree’s shape under microscope. Similar results were reported by Gillespie, (1918); Horsfall, (1954); Walker, (1957); Shiring and Gottlieb, (1966).

Pathogenicity test prove scab symptoms on potato tuber in the experimental field and the retesting confirmed that. Typical results mentioned by Hooker, 1981; Loria et al., (1997). This means that the pathogen have higher potential to attack potato tubers continually in the field during the season. This maybe due to soil PH or others environmental condition. Hochmuth (1998) reported that there are cases where crop production at less than optimum PH is unavoidable. An example is the use of acidic soils for potato scab control. Another example is the alkaline soils of Dade county, where adjustment in rates and placement must be made for that portion of the fertilizer that is fixed by the soil.

The result of neem extract controlling *S. scabies* in the lab showed that there was significant relation between the number of colonies of the organism (*S. scabies*) and different concenterations of neem extract, this may lead to promising natural bactericide of Plant Pathology, specially it is very successful, beneficial, wide spread in pest control and others healthy treatment for humankinds. Similar results of controlling pests were mentioned by Satti, (1991); Siddig, (1991); Schmutterer, (1995).
Data of surveying study showed that there were positive and significant correlation between economic losses due to infection all of infected cultivated seeds, seed source, fertilizer dose, fertilizer application, distance of land from the Nile, the fate of infected tuber and soil type. This may be due to above factors themself. Similar results were reported by Walker (1957), Horst (1969); Western (1971); Buturovic (1972); Horonski and Messfeller, (1972); Khan et al., (1973); Luitiens, (1986); Loria et al., (1997); Christ, (1998). On the other hand Hochmuth, (1998) reported that modern vegetable fertility complex in nature, resulting from the interaction of many factors. One important factor is fertilizer cost, which is a large portion of the crop production expenses. Application of unneeded nutrients to farming inefficiency and, potentially, to ground water pollution. Careful use of fertilizer, therefore will save money and ensure freedom from governmental monitoring and regulation. Also Ahmed, (1999) mentioned that scab of potato reduce the rate of marketing tubers.

No significant correlation between economic losses and sowing date, tool sterility for cutting tuber and land flooding in present surveying, this may be due to traditional methods for potato producer under survey condition.

5.2 Conclusion and Recommendations:

More research work is needed in The Sudan in husbandry practices of controlling plant diseases, so as to decrease the usage of chemical control.

More studies are needed in The Sudan in husbandry practices of controlling common scab of potato.

More studies must be done on neem extract control for plant diseases, bearing in mind the successfull methods of controlling insects.
Encourage research and researchers on linking crop price and disease control cost to make crops marketable and good for marketing.

More studies are needed in The Sudan on community oriented to upgrade levels of producers, farmers and consumers for making good communication to assist in avoiding side effects of plant diseases and also forecasting to protect plants from epidemic diseases.

Need less to prove the importance of separate research centre for Plants Pathology in The Sudan, so as to be the controller.
CHAPTER SIX
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CHAPTER SEVEN

APPENDICES

Appendix 1: Culture media : selective media for (Streptomyces scabies)
A: Potato Dextrose Agar (PDA) was prepared from the following constituents:
- Distilled water 1000.0 ml
- Sliced Potato 200.0 g
- Agar 20.0 g
- Dextrose 20.0 g
B: Potato Dextrose Broth (PDB) was prepared from the following constituents:
- Distilled water 1000.0 ml
- Sliced Potato 200.0 g
- Dextrose 20.0 g

Appendix 2: Statistical analysis:
- N.B. For all tables
- D.F Degree of freedom
- S.S Sum of squares
- M.S Mean Square
- F.C Variance ratio
- N.S Not significant
- * Significant (P = 0.05)
- ** Highly significant (P = 0.01)

Appendix 3a: Varieties of Potato
- V₁ Alpha
- V₂ Drag a
- V₃ Diamond
- V₄ Alpha control
Appendix 3b: Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<td>Feddan</td>
<td>1.036 Acres</td>
</tr>
<tr>
<td>Ha</td>
<td>2.4 Feddan</td>
</tr>
<tr>
<td>Kg</td>
<td>kilogram</td>
</tr>
<tr>
<td>ABS</td>
<td>Agricultural Bank of Sudan</td>
</tr>
<tr>
<td>CIP</td>
<td>International Potato Center</td>
</tr>
<tr>
<td>µ</td>
<td>Micrometer</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeter</td>
</tr>
<tr>
<td>Co</td>
<td>Centigrade</td>
</tr>
<tr>
<td>F°</td>
<td>Fahrenheit</td>
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<td>C.F.U</td>
<td>Colonies Form Unit</td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
</tr>
<tr>
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<td>United Kingdom</td>
</tr>
<tr>
<td>S.M.D</td>
<td>Soil Moisture Deficit</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>mm</td>
<td>Millimeter</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>NO₃</td>
<td>Nitrate</td>
</tr>
<tr>
<td>NH₃</td>
<td>Ammonium nitrate</td>
</tr>
<tr>
<td>PPm</td>
<td>Part per million</td>
</tr>
<tr>
<td>IPM</td>
<td>Integrated Pest Management</td>
</tr>
<tr>
<td>min</td>
<td>Minute</td>
</tr>
<tr>
<td>P.C.N.B</td>
<td>Pentachloro Nitro Benzene</td>
</tr>
<tr>
<td>Shihanab region</td>
<td>60 km North Khartoum State</td>
</tr>
<tr>
<td>fed</td>
<td>Feddan</td>
</tr>
<tr>
<td>U of K</td>
<td>University of Khartoum</td>
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Appendix 4: Mean square values of the effect of application of irrigation and fertilization on rate of infection and yield of four varieties of potato grown at shihanab region during 2002 season.

<table>
<thead>
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<th>Source of variation</th>
<th>d.f</th>
<th>Rate of general infection (%)</th>
<th>% of higher infection</th>
<th>% of medium infection</th>
<th>% of lower infection</th>
<th>% of higher infection at large size</th>
<th>% of medium infection at large size</th>
<th>% of lower infection at large size</th>
<th>% of higher infection at med. size</th>
<th>% of medium infection at med. size</th>
<th>% of lower infection at med. size</th>
<th>% of higher infection at small size</th>
<th>% of medium infection at small size</th>
<th>% of lower infection at small size</th>
<th>Total yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replications</td>
<td>3</td>
<td>11.37 NS</td>
<td>4.47 NS</td>
<td>9.77 NS</td>
<td>8.58 NS</td>
<td>10.36 NS</td>
<td>32.81 NS</td>
<td>30.37 NS</td>
<td>0.97 NS</td>
<td>11.71 NS</td>
<td>11.70 NS</td>
<td>23.12 NS</td>
<td>7.36 NS</td>
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<tr>
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<td>168.36 **</td>
<td>0.28 NS</td>
<td>131.22 **</td>
<td>2.48 NS</td>
<td>188.18 **</td>
<td>546.98 **</td>
<td>289.80 **</td>
<td>40.05 NS</td>
<td>201.00 **</td>
<td>147.90 **</td>
<td>910.58 **</td>
<td>353.78 **</td>
<td>512.80 **</td>
<td>1.20 NS</td>
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<td>44.77 **</td>
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<td>259.46 **</td>
<td>675.99 **</td>
<td>846.59 **</td>
<td>1037.96 **</td>
<td>76.86 NS</td>
<td>172.03 **</td>
<td>187.00 **</td>
<td>249.68 **</td>
<td>124.57 **</td>
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<td>205.86 **</td>
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<td>236.25 **</td>
<td>1447.27 **</td>
<td>466.49 **</td>
<td>161.36 **</td>
<td>183.79 **</td>
<td>61.86 **</td>
<td>120.20 **</td>
<td>211.50 **</td>
<td>104.10 **</td>
<td>189.57 **</td>
<td>1.32 NS</td>
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<tr>
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<td>5.25</td>
<td>9.61</td>
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<td>32.57</td>
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<td>8.29</td>
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<td>C. V(%)</td>
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<td>6.75</td>
<td>6.52</td>
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<td>9.60</td>
<td>15.42</td>
<td>17.03</td>
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<td>6.60</td>
<td>12.76</td>
<td>7.71</td>
<td>13.76</td>
<td>14.02 NS</td>
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N.S., **: Not significant and significant at 0.05 and 0.01 level of probability, respectively.
Appendix (5): Mean square values of the effect of application of irrigation and fertilization on rate of infection and yield of four varieties of potato grown at shihanab region during 2003 season.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f</th>
<th>Rate of general infection (%)</th>
<th>% of higher infection</th>
<th>% of medium infection</th>
<th>% of lower infection</th>
<th>% of higher infection at large size</th>
<th>% of medium infection at large size</th>
<th>% of lower infection at large size</th>
<th>% of higher infection at med. Size</th>
<th>% of medium infection at med. Size</th>
<th>% of lower infection at med. Size</th>
<th>% of higher infection at small size</th>
<th>% of medium infection at small size</th>
<th>% of lower infection at small size</th>
<th>Total yield</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td>45.60 **</td>
<td>1248.76 N.S</td>
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<td>182.73 **</td>
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<td>C. V(%)</td>
<td></td>
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<td>13.83</td>
<td>19.79</td>
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<td>21.08</td>
<td>7.83</td>
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</tbody>
</table>

N.S, *, **: Not significant and significant at 0.05 and 0.01 level of probability, respectively.
Appendix (6): Questionnaire form and the percentage occasion for each variable conducted at the area under study.

<table>
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<th>Item</th>
<th>Variables</th>
<th>Frequency</th>
<th>Percent</th>
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<td>Seed source</td>
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<td>A</td>
<td>Introduced</td>
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<td>1</td>
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<td>A</td>
<td>local companies seed</td>
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<td>A</td>
<td>Stored and introduced</td>
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<td>Total</td>
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</tr>
<tr>
<td>3</td>
<td>B</td>
<td>Sowing date</td>
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</tr>
<tr>
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<td>B</td>
<td>Mid October</td>
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<td>0</td>
</tr>
<tr>
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<td>B</td>
<td>End October</td>
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<td>B</td>
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<td>Total</td>
<td>Total</td>
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</tr>
<tr>
<td>4</td>
<td>C</td>
<td>Tuber cutter tool</td>
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<td>Fertilizer Application</td>
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<td>More than one</td>
<td>100</td>
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</tr>
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<tr>
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<td>Near + far</td>
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</tr>
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<td>19</td>
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<td></td>
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<td>Greater economically</td>
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</tbody>
</table>
Streptomyces scabies

"لا تسبع البكتيريا الدائرة للبطاطس جرب"

"الغرض من دراسة مكافحة مرض مكافحة في الزراعة":"

"الغرض من دراسة مكافحة في النم بذور القمح استعمال القدرة، إضافة إلى دراسة وكمال البكتيريا في الأحمال، إضافة إلى الدراسة العامة، النقاط المماثلة، النسبة السبيكة، النسبة المتوسطة، النسبة العالية).\"

"وبالنسبة للزراعة، توفر دراسة أوضاع "

"الدراسة بخصوص القدرة. حيث أن الدراسة العامية، الإصابة معدل، الإصابة نسبة السبيكة، الإصابة نسبة المتوسطة، الإصابة نسبة العالية).\"

"وبالنسبة للزراعة، توفر دراسة أوضاع "

"الدراسة بخصوص القدرة. حيث أن الدراسة العامية، الإصابة معدل، الإصابة نسبة السبيكة، الإصابة نسبة المتوسطة، الإصابة نسبة العالية).\"
لا يوجد نص يمكن قراءته بشكل طبيعي.